CLIMATIC INFLUENCES ON THE GRAPEVINE:

A STUDY OF VITICULTURE IN THE WAIPARA BASIN

A thesis submitted in partial fulfilment of the requirements for the

Degree of Master of Science in Geography

in the University of Canterbury

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University of Canterbury

2006

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Acknowledgments

The completion of this thesis would not have been possible if not for the help of some very knowledgeable and understanding people. First and foremost, my supervisor Andy Sturman, who I will forever be in a debt of gratitude for his guidance throughout the entire process and especially during the trying times, many thanks. Also to Dick Pharis, the owner of Mackenzie vineyard where the temperature sensors and the weather station were set up, thank you for lending the use of your land and your grapes. To Justin Harrison for the great assistance in the equipment and technical side of the study, whose help I would have been lost without. I would also like to thank those in the Geography and Science department who provided me with understanding and support during a very difficult period.

I would also like to acknowledge the support network provided to me by my family, friends and especially my sister Carly. Without their loving support this thesis would have never eventuated, for that I will forever be grateful.

Abstract

Climate is one of the most important factors influencing where wine grapes can be grown and the quality of wine produced from those grapes. A plants habitat has a profound influence on its growth and development. The surrounding climatic conditions at both the macro- and meso-scales influence the plant-climate miro-scale interactions. The main study site is the McKenzie Vineyard that is owned by Torlesse Wines. The climatic conditions of the surrounding Waipara region was also studied using climate data from the following vineyards; Canterbury House, River Terrace and Waipara West. The overall aim of this research is to improve understanding of the influence of the climatic environment on grapevine development at the meso- to micro-scale. The main findings of the research were firstly, that the most important climatic factor influencing grapevine development and growth is temperature and secondly that there is variability in the temperature across the Waipara Basin. Future research should be conducted for the entire growth season to gain a better understanding of how temperature influences the development of grapevine over the growing season as a whole.

Chapter 1

Introduction

1.1 Introduction

The viticultural and wine industry is a young, increasingly important part of New Zealand's economy. It is a reasonably new industry (in New Zealand) compared to the centuries old wine industry in Europe. This has obviously resulted in the viticulturists of Europe having a very in-depth knowledge of the grapevine and how it interacts with its surrounding environment. They have had many years to create an understanding of which grape variety is best suited to each climate region. Due to the relatively recent development of the industry in New Zealand, the viticulturists do not have the same depth of experience when it comes to the climatic environment and the grapevine. Therefore, there is a need to build on current knowledge of the interaction of the climate and the grapevine in New Zealand, with special reference to specific regions within the country.

This study examines the relationship between spatial and temporal variations of specific climatic factors and the developmental stages of the grapevine within a single growing season. The purpose of this chapter is to outline the important concepts that are the foundation of the interaction of the vineyard with its surrounding environment, the nature of the research conducted, the research aims and objectives of the study and how they will be examined within this thesis.

1.2 Research Background

This section outlines the fundamental components of the study. This includes the wider context of the relationship between climate, the vineyard and the grapevine, the research rationale and the research aims of the thesis.

1.2.1 The relationship between the vineyard and the surrounding environment

The vineyard environment can be defined as a system. Every system, it has inputs and outputs and connections between each component. Within the vineyard environment there are many sub-systems. The three most important can be defined as the soil, vineyard/crop management and climate (Figure 1.1). Due to the overall complexity of the vineyard environment each of the sub-systems cannot be studied by itself. The three sub-systems are interrelated, both indirectly and directly, but the extent of their interaction differs (Smart, 1985; Jackson and Lombard, 1993; Jackson, 2001; Rankine, et al, 1971). Most researchers agree that it is the interaction of all three sub-systems that affects the resulting quality of wine. Therefore, the viticulturist's understanding of how each of the sub-systems influence and interact with each other is essential.

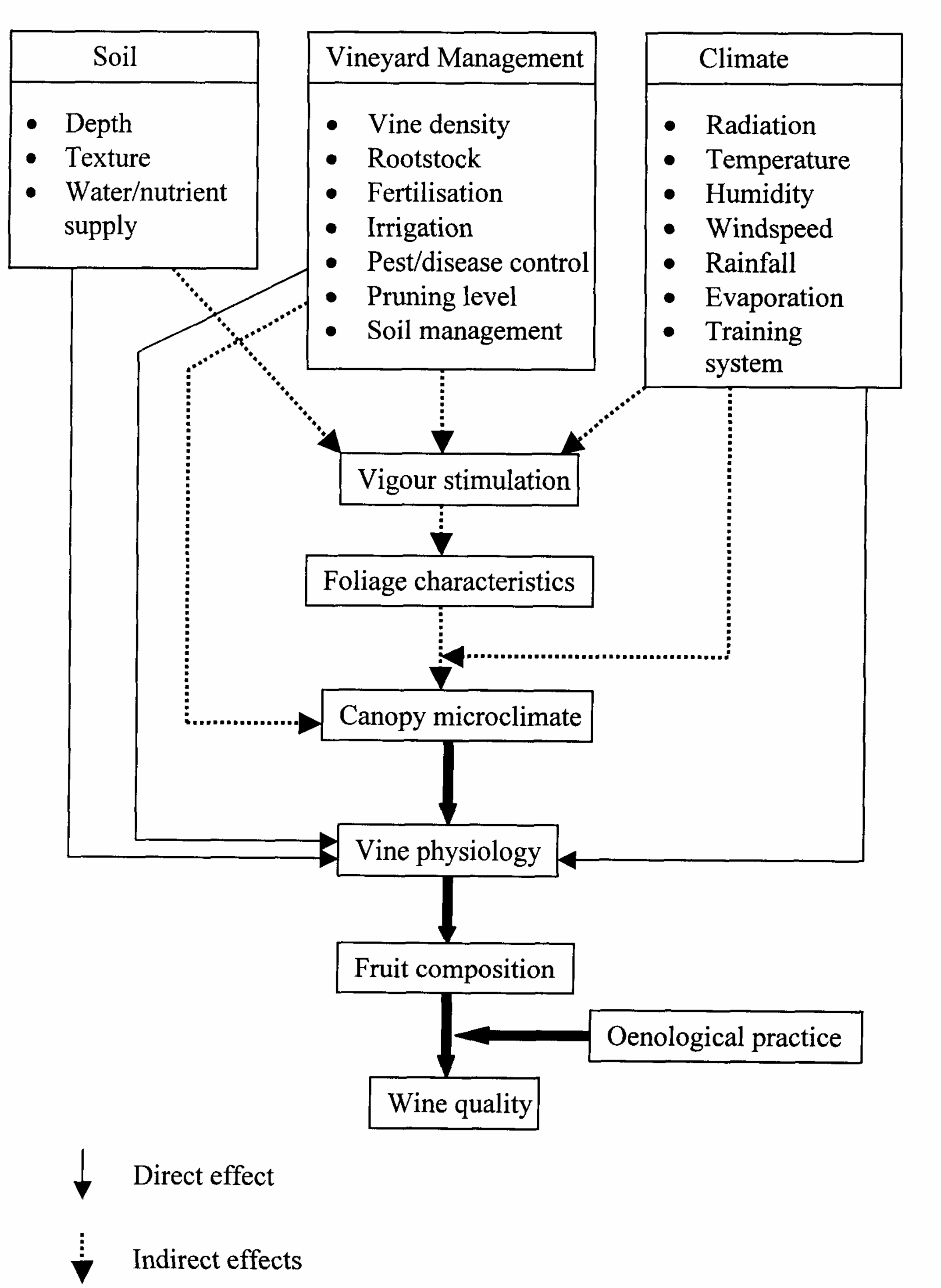

Figure 1.1: Conceptual model to show how soil, climate and vineyard management can affect fruit composition directly or indirectly through canopy microclimate and vine physiology (Source: Weldon, 2003).

1.2.2 Definition of scales

There are a number of climatic processes that operate at differing time and space scales (Figure 1.2). In this study, there are three major climate scales that are considered - the macroclimate, the mesoclimate and the microclimate. The macroclimate is defined as the general climate of a region extending across several hundred kilometres. In this case, the macroclimate can be described as the general climate of Canterbury. Within the macroclimate is the mesoclimate. The mesoclimate is defined as the climate of a small area, such as a valley or a city. At this scale, such variables as local winds, relief, slope and aspect are of substantial significance. In this study, the mesoclimate is the Waipara Basin, located in north Canterbury. Within the mesoclimate is the microclimate. The microclimate is defined as the climate of those parts of the lower atmosphere directly and immediately affected by the features of the Earth's surface. The microclimate of this study is the Mackenzie vineyard within the Waipara Basin, including the immediate surrounding of the grapevine.

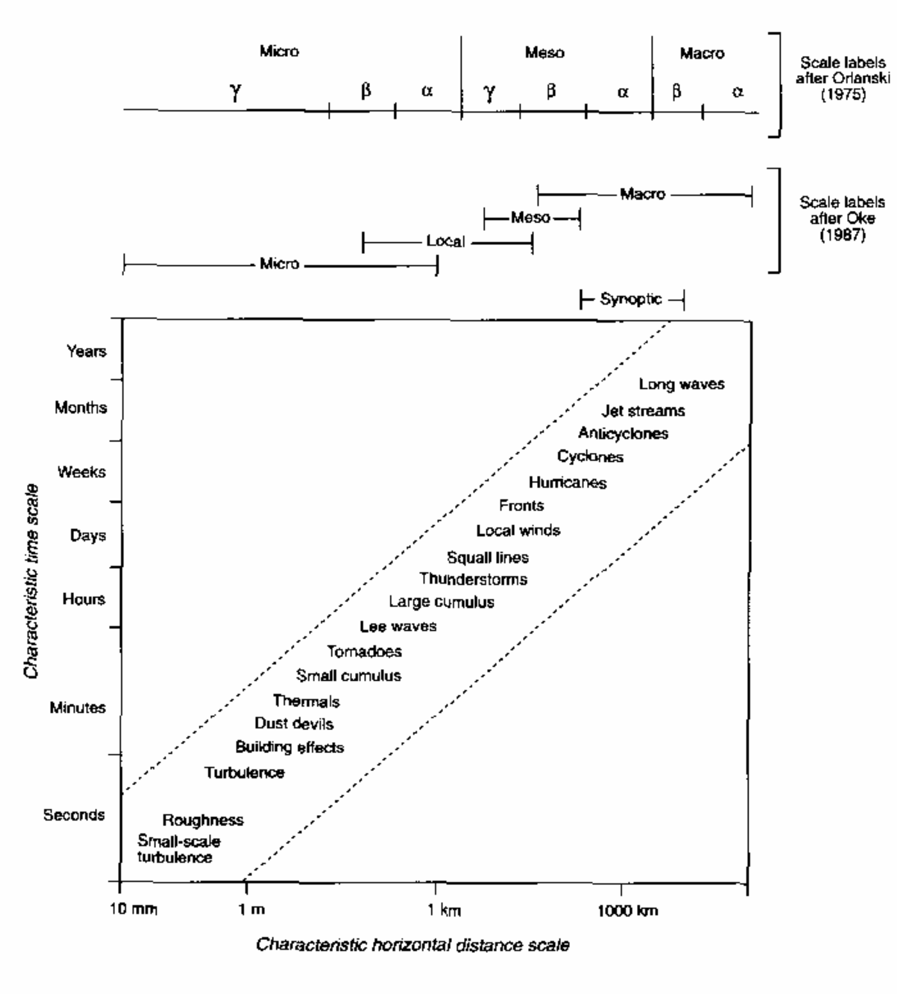

Figure 1.2: Characteristic time and space scales, with associated atmospheric phenomena (Source: Sturman and Tapper, 2001).

1.2.3 Rationale

Of the three scales of climate that effect viticulture - macroclimate, mesoclimate and microclimate - most studies conducted previously have concentrated on the climate at the macro and meso levels. This is due to most of the climate data only being available at either the regional scale or at the "best site" for an area. However, to look in detail at how climatic factors affect the growth and development of the grapevine a micro-scale approach is needed.

Vineyard management consists of controlling many factors within the surrounding environment. These elements can include pests, weeds, soil composition, irrigation and vine canopy management. Successful vineyard management takes into account those factors that can easily be controlled rather than factors that are more difficult to control, such as the climate. Even though the climate cannot be controlled, the effects that it has on the vineyard and particularly the grapevine can be controlled to some extent with the right knowledge. Throughout the growing season, as well as from year to year, the vineyard has to be managed to create optimal climatic conditions within the grapevine canopy.

The rationale for this thesis is that even though there have been significant advances in vineyard management and viticultural technologies, the interaction of the surrounding environment with the grapevine cannot be completely controlled. There is still incomplete knowledge of how the different grape varieties interact with the climatic environment at the micro-scale in the relatively new area of the Waipara Basin. An understanding of this interaction is important for successful vineyard management decision-making, not only in Waipara, but throughout New Zealand as well.

1.3 Research Aims

The overall aim of this research is to improve understanding of the influence of the climatic environment on grapevine development at the meso- to micro-scale. This includes an understanding of:

1. How microclimatic factors influence the development of the grapevine over the growing season in a single vineyard (McKenzie Vineyard) on McKenzies Road in Waipara.

2. The local to regional scale climate processes that make the Waipara region such a good area for viticulture.

These general objectives can be broken down into more specific aims of this study, as follows:

- To compare the physiological response of grapevines of different varieties to micro-climate variations within the McKenzie vineyard.
- To identify the small-scale spatial pattern of warm and cold areas within the vineyard, and their significance for the physiological development of differing grape varieties.
- To examine the effect of key meteorological events (such as frost, windy or cold periods) on grapevine physiological development during the growing season.
- To investigate the variability in climate across the Waipara Basin wine producing area, using meteorological data from a number of different vineyards.

The above aims will be achieved by analysing data obtained using a network of meteorological data sensors established within the vineyard, the record of vine development obtained by the vineyard manager, and meteorological data obtained from other vineyards in the Waipara region.

1.4 Thesis Outline

The purpose of Chapter 1 is to introduce the research topic and to provide an overview of the scale and relationships involved within the study. The second Chapter describes the history and the current setting of viticulture in New Zealand, Canterbury and Waipara. This Chapter sets the scene for the research and how it is relevant in the current viticultural industry. Chapter 3 describes in detail the grapevine development and states the climatic factors that can affect this development. The fourth Chapter explains what a “cool climate” is and how it influences the different grape varieties. The fifth Chapter gives an account of the methodology of this study, which is followed by Chapter 6, which presents the results. Chapter 7 discusses the resulting findings of the study. The final Chapter summarises the main findings, their implications and gives suggestions for future research options.

1.5 Summary

The purpose of this chapter is to outline the research, the aims and objectives of the study and to provide an overview of how the thesis will be structured. The relationship between the vineyard and its surrounding environment, how it can be can be defined as a system with inputs, outputs and connections between each component was explained. The definition of the scales at which the study is conducted was also stated. Through these the aims and objectives of the study where able to put into context and established. Also the importance of this type of research to the New Zealand viticultural and industry

Chapter 2

Viticulture in New Zealand

2.1 Background/ History

In New Zealand, religious missionaries and French settlers first planted grapes for winemaking in the early nineteen-century. At first, the development of viticulture was slow, especially in the North Island, due to the climate being unsuitable for grape growing and making wines the traditional European way. This was due to high rainfall and humidity, which caused disease. The European methods were not well-suited growing grapes in the New Zealand cool climate. Hybrid grapes were introduced, but they did not produce quality wines. In the 1970's, New Zealand experienced a rapid expansion and growth of its wine industry. Corbans and McWilliams were the two major winemakers until the 1980s, but there was rapid growth of Montana, Villa Maria, Cooks, Delegats, Penfolds and Nobilos. Today there are two major companies, Montana and Corbans, with quite a few medium to large companies such as Villa Maria and Nobilos, and many small to medium specialist or boutique wineries. The mid 1980s also saw a shift towards planting grapes that were aimed more for the export market. Overall, due to New Zealand's maritime climate, summer temperatures never becoming too hot and ripening occurs in late summer and autumn when the temperatures are generally cool, so the high quality wines can be obtained.

New Zealand has ten main wine growing regions (Figure 2.1). Within each of these regions there is a variety of wines, grape varieties, soils and climates (Table 2.1). New Zealand's wine growing regions are located between the latitudes of 36 to 45 degrees. Diverse arrays of wine styles are produced due to the grapes grown in a variety of climate and soil types. The equivalent region in the northern hemisphere would run from Bordeaux (between the latitudes of 44 and 46 degrees) down to southern Spain (New Zealand Wine and Grape Industry, 2004).

Figure 2.1: The major wine regions of New Zealand (source: www.wineanorak.com).

Table 2.1: The major wines, grape varieties, soils and climates of New Zealand (source: Jackson and Schuster, 2001, p. 42).

District	Wines	Varieties	Soil Type and Position	Annual Rainfall (mm)	Heat Units in growing season (^{o}C)	LTI
Northland	Red and white table wines, some fortified	Cabernet Sauvignon, Chasselas, Palomino, Pinotage, Müller-Thurgau.	Shallow clay soils over sandy-clay subsoils. Flats and mild slopes	1600	1300-1400	450
Auckland (Henderson and Kumeu)	White and red table wines, some fortified and sparkling	Müller-Thurgau, Pinotage, Chasselas, Cabernet Sauvignon, Merlot, Gewürztraminer, Pinot noir, (including Gamay de Beaujolais), Sémillon and Sauvignon blanc.	Shallow clays over hard silty-clay subsoils. Mainly flats.	1500	1300-1350	440
Waikato	White and red	Müller-Thurgau, Pinotage, Chasselas, Cabernet Sauvignon, Chenin blanc and others.	Heavy loams over clay subsoils. Flats and mild slopes.	1100-1200	1250-1300	414
Gisborne	White and red table wines, fortified and sparkling	Palomino, Müller-Thurgau, Pinotage, Chasselas, Cabernet Sauvignon, Chenin blanc, Chardonnay, Merlot, Sauvignon blanc, Riesling.	Fertile, alluvial loams over sandy or volcanic subsoils. Flats	1000-1050	1250-1300	394
Hawkes Bay	White and red table wines, some fortified and sparkling	Müller-Thurgau, Chasselas, Cabernet Sauvignon, Pinot Gris, Chardonnay, Merlot, Sauvignon blanc, Riesling.	Clay loams of medium to high fertility over gravelly or volcanic subsoils. Flats	750-800	1200-1250	384
Wairarapa	White and red	Pinot noir, Chardonnay, Pinot Gris Merlot ,Riesling.	Deep stony and silt loams over gravel.	1050	1080-1150	332
Nelson	White and red	Müller-Thurgau, Slyvner,Gewürztraminer, Pinot noir, Chardonnay, Riesling, Refosco, Cabernet Sauvignon.	Clay loams over hard clay subsoils. Slopes.	1000-1250	1050-1100	320

Table 2.1 (contd)

District	Wines	Varieties	Soil Type and Position	Annual Rainfall (mm)	Heat Units in Growing Season (°C)	LTI
Marlborough	White, red and sparkling	Gewürztraminer, Müller-Thurgau, , Cabernet Sauvignon, Pinotage, Chardonnay, Riesling, Sauvignon blanc, Pinot noir, Muscat Dr. Hogg Merlot, Pinot meunier.	Silty-alluvial loams over gravelly subsoils. In parts compacted silt or clay pans of various thickness and depth are found. Flats.	650-750	1150-1250	327
Canterbury	White and red	Gewürztraminer, Müller-Thurgau, Cabernet Sauvignon, Pinotage, Chardonnay, Riesling, Sauvignon blanc, Pinot noir, Pinot gris, Pinot noir.	Alluvial silt loams over gravel subsoils in the central parts. Chalky loam soils often rich in limestone in the northern part. Gentle slopes.	600-750	900-1100	277
Central Otago	White and red	Gewürztraminer, Pinot gris, Chardonnay, Riesling, Sauvignon blanc, Pinot noir.	Silt loams with mica and schists. Moderate to steep slopes.	400-450	850-1000	260

2.2 Wine Styles of New Zealand

The wine style depends on a few important factors: firstly, the variety of grape that is chosen and then grown; secondly, the terroir that it is grown in; and the skill of the winemaker. New Zealand has many wine styles, and the following are the more well known ones.

2.2.1 Cabernet Sauvignon

Cabernet Sauvignon was first planted in New Zealand in 1832 by James Busby. It was well-liked with the country's original winemakers until phylloxera destroyed most of the vines later in the century. In the Hawkes Bay in the mid-1960's, Cabernet Sauvignon was again planted and within a couple of decades it was planted in all regions around New Zealand (http://www.nzwine.com/regions). Cabernet Sauvignon does particularly well in the warmer regions of northern New Zealand, but there are quite a few very good Cabernet Sauvignons produced in Canterbury. The noble red wine is often the base for blends, with Merlot, Cabernet Franc, even Pinot Noir as it can be relied on for tannins, which give astringency and good palate structure to a wine. A typical Cabernet will be strong and powerful, sometimes with an almost metallic hint (http://canterburyfare.co.nz/new-zealand/wine/winestyles.htm). The main characteristics of a Cabernet based wine are the fullness of varietal character, depth in bouquet and flavour, coupled with high acidity and tannin content (Jackson and Schuster, 2001).

2.2.2 Merlot

Merlot was first planted in New Zealand in the 1980's. The total plantings are now approaching those of Cabernet Sauvignon. Merlot also does particularly well in the warmer regions of northern New Zealand (http://www.nzwine.com/regions). It is often blended with Cabernet Sauvignon, but a good Merlot, although softer, can stand alone with good strength and definite berry fruit aroma and flavours, which have come straight from the grapes. (http://canterburyfare.co.nz/new-zealand/wine/winestyles.htm).

2.2.3 Pinot Noir

Pinot Noir was first planted in the Auckland region during the mid-1970s. Within a decade, the wine was being produced in the Wellington region (particularly in Martinborough) and Hawkes Bay, plus most of the regions in the South Island. Due to the early competition successes from the Canterbury and Martinborough regions, and the demand for Pinot noir as a component in high quality bottle fermented sparkling wine, this variety has become the most widely planted red grape variety in the country and one of New Zealand’s most prestigious and acclaimed wine styles (http://www.nzwine.com/regions).

2.2.4 Chardonnay

In New Zealand, Chardonnay was first introduced in the 1830’s. However, due to the phylloxera outbreak in the late 1800s it disappeared. In the 1970s, it reappeared again, being planted in large commercial quantities. As its popularity rose, it was eventually planted in every region in the country and is now New Zealand’s most widely planted grape variety (http://www.nzwine.com/regions). Chardonnay grapes can grow in a broad range of cooler climates and is a very popular wine style. A good Chardonnay can and will age well, and can mature into an appealing and complex wine. (http://canterburyfare.co.nz/new-zealand/wine/winestyles.htm). Chardonnay wine has a fine and very distinctive varietal flavour and aroma (Jackson and Schuster, 2001).

2.2.5 Sauvignon Blanc

A vineyard in Auckland in the 1970s was the first place Sauvignon Blanc was grown. The cuttings from this first vineyard were transported to the Marlborough region in 1973 for their first vineyards, although the first wine made in commercial quantities did not appear until 1980. By the early 1990s, Sauvignon Blanc had forged its way into the wine industry and is probably the best known of New Zealand's export wines. It now represents almost one quarter of all the vines planted in New Zealand, which makes it the second most planted grape variety (http://www.nzwine.com/regions).

Canterbury Sauvignon Blanc usually has the same typical style of the Marlborough Sauvignon Blanc where the grapes are shaded; giving it grassy, even vegetative primary characters. With the riper fruit, melon and citrus flavours are often present. (http://canterburyfare.co.nz/new-zealand/wine/winestyles.htm).

2.3 Canterbury region

The Canterbury region has New Zealand's most extensive lowlands. Braided rivers cross the plains leading from the mountain ranges to the sea in the east. Canterbury is New Zealand's fourth largest wine producing region, from Waipara in the north to Pleasant Point (near Timaru) in the south. Overall, it holds 4% of the total vineyard area, (more than the Auckland, Wairarapa and Nelson regions). It also possesses 10% of New Zealand's wine producers. In 1986, there were 35 hectares of wine production land. In 1998, this increased to 325 hectares, and in 2001 the production area was 614 hectares (Cooper, 2002).

The Canterbury region has over 160 years of viticultural history. Grapevines (Vitis vinifera) first arrived in the Canterbury region with the earliest French settlers in 1840. This was 10 years before the formal settlement of Canterbury by the British. These settlers first planted grapevines in Akaroa in the 19th century. However, a wine industry failed to develop. There were many reasons why this happened. Firstly, the British colonists knew little about viticulture in comparison with the French and the Germans, and there were significant cultural differences between the people on the plains (British) and the people on Banks Peninsula (French). Also, the French settlers had little money and few had a strong viticultural background. The remote location of the settlement hindered development. As well, the vines were subjected to extensive bird damage and the grape disease powdery mildew (Oidium) (Jackson *et al*, 2002). The contemporary age of Canterbury wine comes from the research conducted by Dr David Jackson at Lincoln University. In 1973, research was focused on the suitable of grape varieties for Canterbury's climate. The trials showed that the grapes produced in Canterbury had high levels of sugar and high acidity. It was found that Canterbury was 'promising' for Pinot Noir and Chardonnay, and somewhat 'borderline' for Sauvignon Blanc and Cabernet Sauvignon due to them being a mid to late season ripener. In 1978, the first commercial vineyard was set up at St Helena, on Coutts Island, 20kms north of Christchurch (Cooper, 2002). Now on the Canterbury plains, Pinot Noir, Chardonnay, Pinot Gris and Riesling are extensively planted. However, it is known that Pinot Noir and Riesling are the regions most notable wines.

The Canterbury regions vineyards are split up into two sub-regions; the first, the flat plains surrounding Christchurch and the second, the undulating terrain of the Waipara Basin.

2.3.1 Waipara

Grapes were first planted in the Waipara district in the 1960's. There was a need in the area to find alternative crops due to the trouble involved in farming the traditional pastoral way with the difficult climate, and especially due to the droughts that often occurred during summer. Originally, in 1917, farms had been divided, based on fertility, out of the former Glenmark estate of George Moore. 400ha of this estate on Weka Plains was brought by John McCaskey. The soil was unfertile and stony, unsuitable for traditional pastoral farming. This led to John McCaskey finding a crop that could "grow in a desert" (Jackson *et al*, 2000, p. 60). John McCaskey therefore attempted to grow grapes in the mid 1960's, although he failed due to lack of irrigation. He tried again in 1981 following the implementation of the Glenmark irrigation scheme, and this time he succeeded. John McCaskey eventually subdivided his land into 19 vineyards. In 1982, trials for grapes were also conducted at what is now known as Waipara Springs. In 1990, Waipara Springs opened the first vineyard restaurant in Waipara, and this was the first of many, including Canterbury House, Glenmark and Pegasus Bay. During the 1990s to the present day, a majority of the new plantings in Canterbury have occurred in the Waipara Basin.

Waipara is located 69km north of Christchurch. The area was traditionally a dairy and cattle farming area. However, due to noteworthy droughts the area has experienced a change in emphasis from the more traditional pastoral type farming to grape growing. The vineyard area expanded during the 1970s and 1980s. Chardonnay and Pinot Noir are the most widely planted grape varieties in Canterbury, making up about 60% of the region's vineyards. Riesling is the third most popular variety with Sauvignon Blanc in fourth place (New Zealand Wine and Grape Industry, 2003).

The total area under production in Waipara increased from 230ha in 2001 to 248 ha in 2002. It is projected to increase to 367ha by the year 2005. In 2002, the predominant wine varieties were Pinot Noir at 33% of the producing area, Chardonnay 22%, Sauvignon Blanc 16%, Riesling 14% and Pinot Gris 4%. By 2005, it has been forecast that Pinot Noir will increase to 43% of the production area, followed by Riesling at 15%, and finally Sauvignon Blanc with 15%. Currently, the total production area of Waipara makes up 2% of the total New Zealand wine producing area. This is projected to stay unchanged (Bank of New Zealand, 2002).

The Waipara area is currently experiencing a significant amount of interest, resulting in the expansion of current vineyard operations, as well as the development of new vineyard developments and the establishment of new wineries.

Table 2.2: Vineyard producing area in New Zealand (source: New Zealand Winegrowers Vineyard Surveys,2006).

Grape Variety (hectares)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Muller Thurgau	712	627	537	520	430	377	307	256	155	137
Chardonnay	1,466	1,618	2,006	2,449	2,858	3,303	3,427	3,515	3,617	3,804
Sauvignon Blanc	1,140	1,453	1,678	2,008	2,485	2,843	3,685	4,516	5,897	7,043
Chenin Blanc	143	134	139	154	150	127	113	108	72	58
Gewurztraminer	93	85	85	103	145	156	178	197	210	257
Riesling	276	314	343	432	503	493	529	653	666	811
Muscat Varieties	199	184	177	191	188	145	135	134	136	139
Semillon	186	190	232	215	235	227	233	257	306	240
Reichensteiner	72	60	74	65	64	52	47	59	61	59
Pinot Gris	21	32	61	90	130	157	232	316	381	489
Cabernet Sauvignon	499	507	555	653	671	744	745	741	687	614
Pinot Noir	431	495	596	826	1,126	1,491	2,029	2,624	3,239	3,757
Pinotage	76	83	64	65	75	81	87	82	82	85
Merlot	302	346	405	535	674	912	1,077	1,249	1,487	1,492
Cabernet Franc	73	70	88	111	121	148	170	180	213	180
Syrah	22	30	40	51	62	87	117	134	183	238
Malbec	14	20	25	49	69	101	116	152	168	163
Other & Unknown	885	1,162	475	483	211	204	560	627	249	1,463
Total	**6,610**	**7,410**	**7,580**	**9,000**	**10,197**	**11,648**	**13,787**	**15,800**	**17,809**	**21,002**

by Region (hectares)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Auckland	193	191	321	345	393	390	448	461	591	514
Waikato/Bay of Plenty	117	90	100	100	119	130	137	142	151	148
Gisborne	1,165	1,180	1,424	1,447	1,681	1,652	1,774	1,885	1,810	1,890
Hawkes Bay	1,794	1,744	1,829	2,336	2,443	3,132	3,463	3,702	3,873	4,249
Marlborough	2,155	2,655	2,747	3,477	4,054	4,561	5,731	6,831	8,539	9,944
Nelson	97	115	161	175	203	324	398	485	548	646
Canterbury	213	190	350	363	442	446	482	601	716	853
Otago	92	135	210	207	280	322	534	703	844	978
Other & Unknown	610	930	226	269	255	291	345	395	457	1,001
Total	**6,610**	**7,410**	**7,580**	**9,000**	**10,197**	**11,648**	**13,787**	**15,800**	**18,266**	**21,002**
Wairarapa	174	180	212	281	327	380	475	595	737	779

* forward estimate.

2.4 Summary

Since the first days of the contemporary revitalization of wine production in New Zealand, there have been significant changes in the attitudes of the public towards wine. At the start of the 21st century, New Zealand wine was very poorly appreciated. Today wine has become an important part of the social lubricant of hospitality, both nationally and internationally through tourism. Present-day consumers now have more choice then ever and the wine industry's success is determined by their purchasing power. Canterbury wine is only one small part of a progressively more competitive world wine market. This competition will necessitate winemakers to continue to improve the overall quality of the wine, the value, the marketing effort and the overall competitiveness.

Chapter 3

Grapevine Development and Climatic Factors

3.1 Introduction

A plant's habitat continually influences its growth and development, and the climatic environment plays an important part in this. The surrounding climatic conditions at both the macro- and meso-scale levels influence both the vineyard environment and the plant-climate micro-scale interactions (Weldon, 2003).

Out of all cultivated plants, the grapevine is considered one of the most responsive to its surrounding environment (Becker, 1984). The climate has a principal influence on both the quantity and quality of the resulting wine, and most importantly on the phenological stages of the vine plant. Temperature especially plays a vital role due to its part in regulating the synthesis and decomposition of certain hormones in the plant during the growing season (Jackson and Schuster, 1997).

The first part of this chapter describes the overall phenology of the grapevine. This is followed by a description of the structure of the grapevine. The annual growth cycle of the grapevine is explained with particular reference to each stage of growth. Lastly the climatic factors that affect grapevine growth are stated in detail.

3.2 Grapevine Phenology

Phenology is described as “the study of natural phenomena that recur periodically in plants and animals, and of the relationship of these phenomena to climate and the changes in seasons” (Coombe, 1987, pp 139). The aim is to explain the variation between seasons by making correlations between certain weather indices and the dates of particular growth events and the intervals between them. Therefore, for the grapevine, emphasis is placed on its growth and developmental cycle. Phenological data are very important to the viticulturist. The data represent an indispensable instrument in vineyard management. For example, they are useful when making informed decisions about soil management, irrigation, pest and disease control, canopy management, harvesting and so forth (Coombe, 1988). A phenological description of the grapevine was developed by Eichhorn and Loernz in 1977, as shown in figure 3.1.

Figure 3.1: Stages in grapevine development from dormant bud to leaf fall (source: Coombe 1987).

The description of each stage within the above diagram is as follows:

01 Winter dormancy: winter bud scales more or less closed.

02 Bud swelling: buds expand inside the bud scales.

03 Wool (doeskin stage): brownish wool clearly visible.

05 Bud burst: green shoot first visible.

07 First leaf unfolded and spread away from the shoot.

09 Two or three leaves unfold.

12 Five to six leaves unfolded; inflorescence clearly visible.

15 Inflorescence elongating; flowers closely pressed together.

17 Inflorescence fully developed; flowers separating.

19 Beginning of flowering; first caps falling.

21 Early flowering: 25% of caps fallen.

23 Full flowering: 50% of caps falling.

25 Late flowering: 80% of caps fallen.

27 Fruit set: young fruits beginning to swell, remains of flowers lost.

29 Berries small; bunches begin to hang.

31 Berries pea-sized; bunches hang.

33 Beginning of berry touch.

35 Beginning of berry ripening; beginning of loss of green colour (verasion).

38 Berries ripe for harvest.

41 After harvest, end of wood maturation.

43 Beginning of leaf fall.

47 End of leaf fall.

3.3 Structure of the grapevine

Grapevines can be divided into two basic portions; the roots (underground) and the trunk, arms and shoots (above ground) (Figure 3.2). The parts of the vine can be classified depending on the functions they perform. There are two groups of parts. The first group carries out the vegetative activity; the roots, trunk, shoots and leaves. This group helps to keep the vine alive through the absorption of water and minerals from the soil, transpiration, respiration, growth, the manufacture of carbohydrates and so forth. The second group consist of the flowers, which serve to produce seeds and fruit (Winkler *et al.,* 1974).

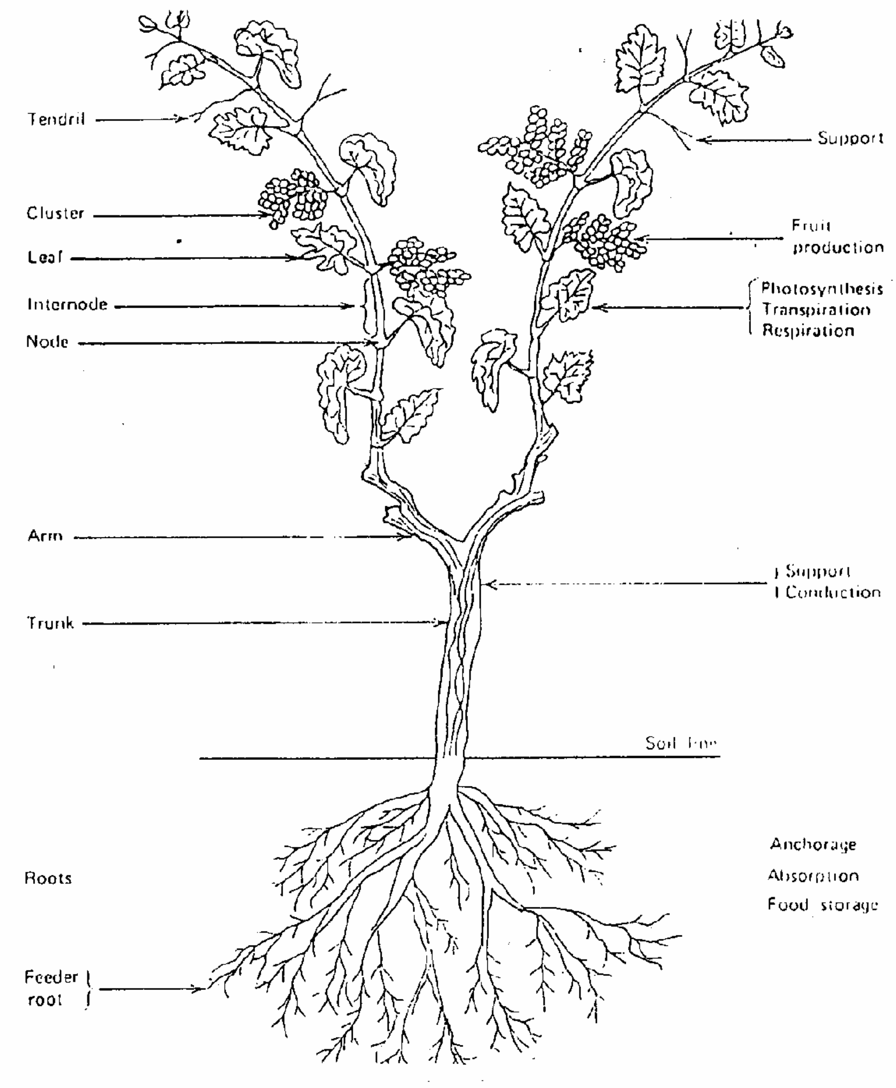

Figure 3.2: Structure of the grapevine (source: Weaver, 1976).

3.4 Annual Cycle of Grapevine Growth

Like most plants, the grapevine has an annual cycle of growth. Figure 3.3 illustrates the stages in the annual life-cycle of the vine. A growing season for the purpose of this study is defined as the period from the breaking of dormancy through the stage of growth to the end of leaf fall, when the grapevine enters dormancy again.

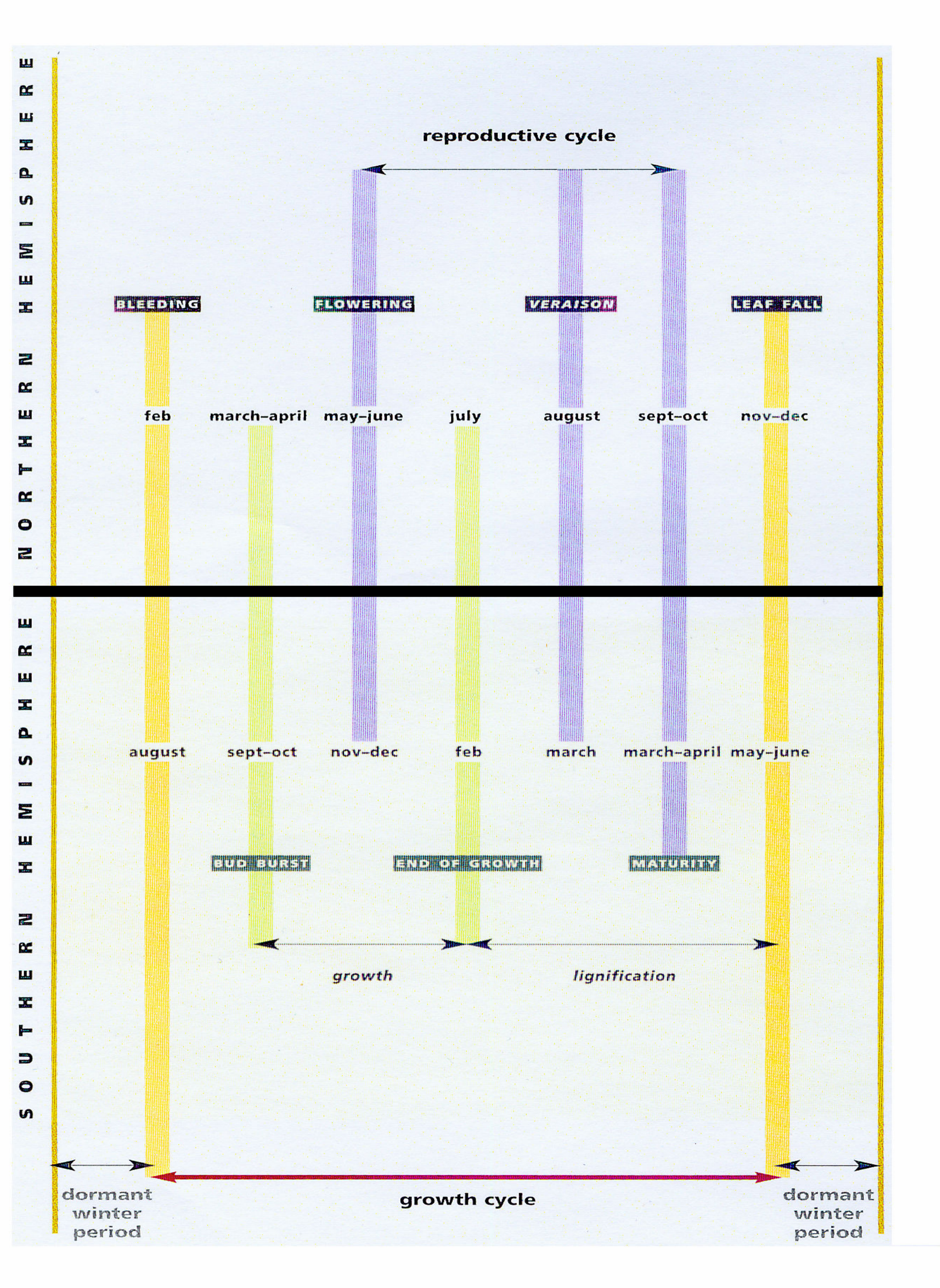

Figure 3.3: Growth cycle of the grapevine (Source: Galet, 2000).

3.4.1 The Dormant Season

The dormant season commences in autumn in southern hemisphere, when the vine sheds its leaves – stages 43 and 47 in Figure 3.1. The dormant season can be divided into periods of quiescence and rest. Quiescence is defined as the period of growth controlled by external factors. Rest in the grapevine is when internal factors prevent growth despite favourable environmental conditions. In temperate regions during winter, much of the starch of the vine is converted into sugars which protect the vine against low temperature injuries (Weaver, 1976). The grapevine begins to break out of dormancy when the air temperatures begin to rise.

2.4.2 Bleeding of the Vine

The first external sign that the grapevine is breaking dormancy and is commencing annual growth is the bleeding of the vine. It is initiated by the bleeding of the sap from the xylem. Bleeding depends on the activity of living root cells so the time of bleeding usually signifies that there is root activity or growth. It has been suggested that the bleeding occurs when the soil temperature at a depth of 25cm reaches a temperature of 10.2^{o}C. Bleeding begins suddenly and rapidly increases in intensity after which it then decreases slowly. The quanity of liquid lost by the vines varies but may be up to 5.5 litres per vine and while the vine is not injured by the bleeding, vines should be pruned at a time so that they will not bleed too much (Winkler, 1974; Weaver, 1976)

3.4.3 Bud Burst

In Figure 3.1, stages 2 to 7 represent bud burst. Bud burst occurs when the mean daily temperature reaches about 10^{o}C. It has been suggested by Pongraz (1978) that it takes between twenty and thirty days from the time the vine starts bleeding to the time the buds begin to open. The factors that affect the date of bud burst include grape variety, the date of winter pruning and the method of pruning, vigour of the vine, and the composition and temperature of the soil.

3.4.4 Growth of the vine

The period following bud burst, is one of active growth. From bud burst in September, the grapevine shoots grow very rapidly both in thickness and in length. The leaves, tendrils and clusters develop very rapidly (Weaver, 1976). As temperature increases shoots may attain a daily growth rate of about one inch. Growth does not occur in all parts of the vine; instead growth is limited to tips of the roots. This is represented as stage 5 in Figure 3.1. As temperatures rise, the rate of growth increases rapidly up to the point at which the berries increase in size, which corresponds with stage 27 in figure 3.1. As the berries increase in size,. the growth of the vine slows down, at first it rapidly slows, then slows down before gradually decreasing altogether (Winkler, 1974).

3.4.5 Ripening of the wood and the dropping of the leaves

The ripening of the wood is one of activity that important for those vines in cold areas and indeed for vines in general as it allows for the vine to be able to survive cold weather. The storage of the food provides the nutrients that will allow the vine to grow earlier in the following growing season (Winkler, 1974).

After shoots have attained their full length and thickness, the shoots start to develop a brownish/red hue which spreads from the base of the shoot to the tip. Well matured canes contain large quantities of store food, are well lignified, have bark that can be torn off and break when the are bent. The presence of large quantities of water in the tissues of badly ripened canes is the reason why they are unable to withstand the cold of winter. The ripening of the wood occurs from January through to leaf fall. This is shown as stages 27 to 47 in Figure 3.1. Wolpert and Howell (1985) have suggested that vegetative maturity is and integral feature of the first stage of vine acclimation – the ripening of the wood and storing of food so the vine may survive over winter. If vegetative maturity is not reached early enough, then the vine may have not fully acclimatised prior to the onset of frosts and cold winter.

3.4.6 Inflorescence

The first stage in the grapevines reproductive cycle is inflorescence. This is shown in Figure 3.1 as stages 12-17. If there are circumstances that disturb the normal cycle of production of inflorescence, the following year there will be fewer inflorescences created. This means that for the following season yield will be greatly reduced. Factors such as over cropping, severe drought and the presence of downy mildew can be responsible for reducing the number of inflorescences (Weaver, 1976).

3.4.7 Floraison

This period is when the caps fall from the flowers. It is represented in Figure 3.1 as stages 19-25. The factors that influence blooming are the weather, the grape variety, the year, the day length and the mean daily temperature. Very few flowers will open at temperatures below 15.6^{o}C, but as the temperature rises to between 18.3 and 21.1^{o}C blooming increases very rapidly. However, if temperatures rise over 37.8^{o}C flowering is retarded, although the flowers are not damaged (Winkler, 1974). The number of days that the grapevine is in bloom is very dependent on the weather, although it usually lasts between 8 and 10 days. In cold rainy weather the caps may not fall form the flowers therefore reducing the amount of fruit setting.

3.4.8 Berry Set

Berry set is the result of effective pollination which has achieved fertilisation and seed development. This is represented in Figure 3.1 as stage 27. Most grape varieties display very similar berry set formations. The length of the berry set period varies from region to region and is very dependent on temperature. If high temperatures occur during florasion there can be reduced berry set in some grape varieties. Water stress at this time can also cause poor berry set (Winkler, 1974).

3.4.9 Growth of the berries

There are three phases in the growth of the berries (increase of berry weight). The first phase is a period of rapid growth until the seed reaches its mature size; the second phase is a period of slow growth, and the third phase is another period of rapid growth ending in maturity, indicated by the colour and the ratio of soluble solids (Brix) to acid. These stages are shown in Figure 3.4, and represented in Figure 3.1 as stage 27 to 29.

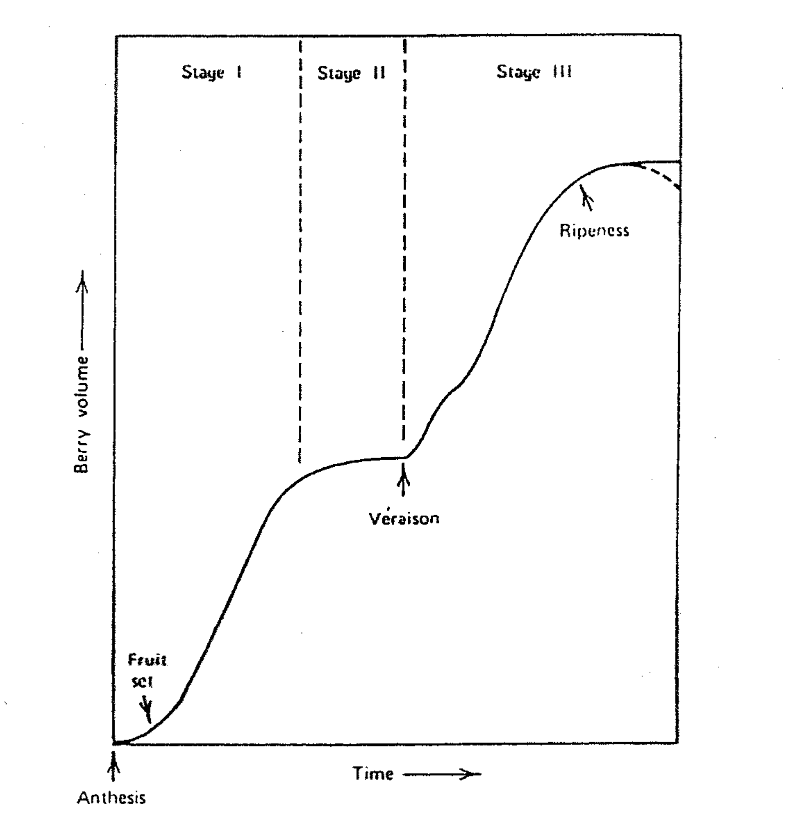

Figure 3.4: The growth curve of the berry (source: Weaver, 1976).

In the initial period of rapid growth the berries remain firm and green and are characterised by rapid acid accumulation. Cell division is rapid in this time. In most grape varieties, this period last 5-7 weeks. Sugars are produced by the vine but at this point they are still being used to help the growth of the shoots, leaves and roots. This stage is represented by stages 27 and 29 in figure 3.1.

In the second period of growth of the berries has slowed considerably. The berries have the highest levels of acid they will have and sugar accumulation begins. This period lasts 2-7 weeks. During this period the growth of the shoots, leaves and roots ceases so that the sugar may begin to accumulate in the berries. This second stage is represented by stage 31 in figure 3.1.

The third period is one of rapid growth exceeding the rate seen in period one. Through this period the berries accumulation of sugar acids decrease, the texture of the berry begins to soften, the skin assumes its ripe colour and the aroma of the ripe fruit develops. This period usually lasts for 5-8 weeks. The point that at which the berries accumulate their ripe coloration is termed verasion. At the time of verasion the berries change from and an acid accumulating organ to that of a sugar accumulation organ. The end of this third period marks the maturity of the fruit at which point they are at their prime and the best for harvesting. These stages are represented by stages 33-38 in figure 3.1.

Following the ripe stage of the berries is an overripe stage during which any changes in the berries are detracting rather than adding to its quality. During this stage the berries are highly susceptible to disease and are likely to split and rot whilst the balance of individual sugars and acids shift to less desirable combinations.

3.5 Climatic Factors Affecting the Grapevine

There are a number of climatic factors that affect the grapevine and its development. These include precipitation, humidity, frost, wind velocity, solar radiation and temperature. However, the most essential climatic factor influencing viticulture is temperature (Becker, 1985; Coombe, 1987; Jackson and Schuster, 1997). Temperature influences many different processes involved in grapevine development. It also influences the levels of certain elements within the berry, for example sugar and acidity (Jackson, 2001).

3.5.1 Temperature

Optimum temperature range for grapevine growth

There have been numerous studies conducted on the interaction between growth and temperature. This has led to the deduction of an overall optimum temperature range of 25°C and 32°C (Jackson, 2001). Any temperature below this optimum range causes vegetative growth to become limited. Temperatures above the optimum range reduce the grapevines photosynthesis rate due to the increase in respiration (Gladstone, 1992). Photosynthetic activity is optimal at 24°C for cool climates (explained more in depth in the next chapter) grapes and 28°C for the warm climate grapes. Lombard and Richardson (1979) have devised a temperature response curve graph (figure 3.5). It shows the grapevines development rate rising and falling with the increase in temperature above the base value temperature of 10°C.

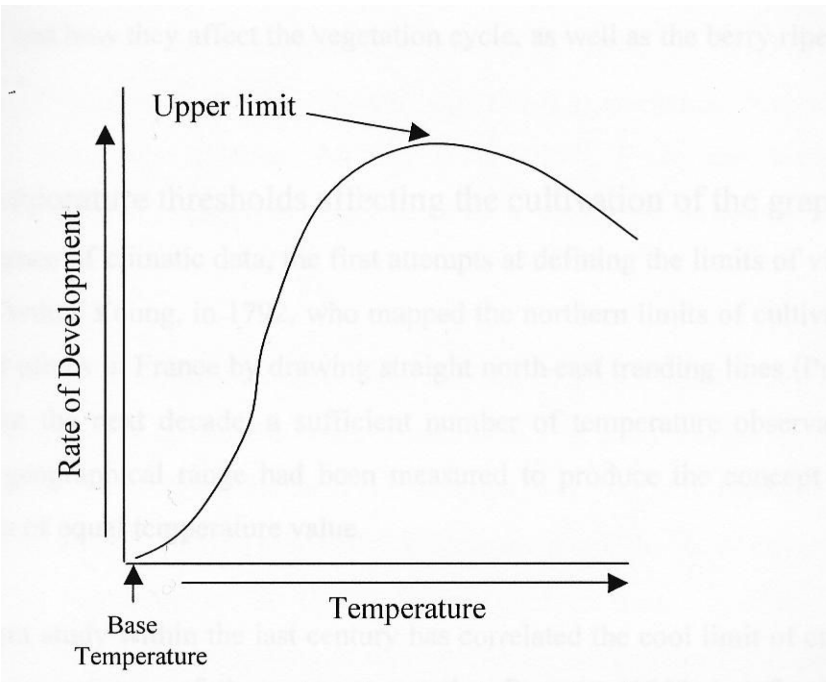

Figure 3.5: Temperature response curve graph (Source: Lombard and Richardson 1979)

Minimum temperature for growth

As described earlier, the development of the grapevine responds to certain temperature thresholds. The temperature control of grapevine development influences the global distribution of wine producing areas around the globe (Figure 3.6). Grape cultivation occurs mainly between the latitudes of 30^o to 50^o, which generally equates to mean annual temperatures of 10^oC and 20^oC (Jackson, 2001). Studies have shown that grape development and the initiation of bud burst will not begin until a temperature of between 7^oC and 11^oC is reached (Jackson and Spurling, 1988; Fitzharris and Endlicher, 1996). However, this threshold temperature also depends on the latitude, grape variety and the year (Galet, 2000). As the temperature increases above this threshold, growth occurs within all parts of the grapevine until the optimal rate growth occurs. Any temperature higher than this causes growth to decline and eventually stop all together (Jackson, 2001).

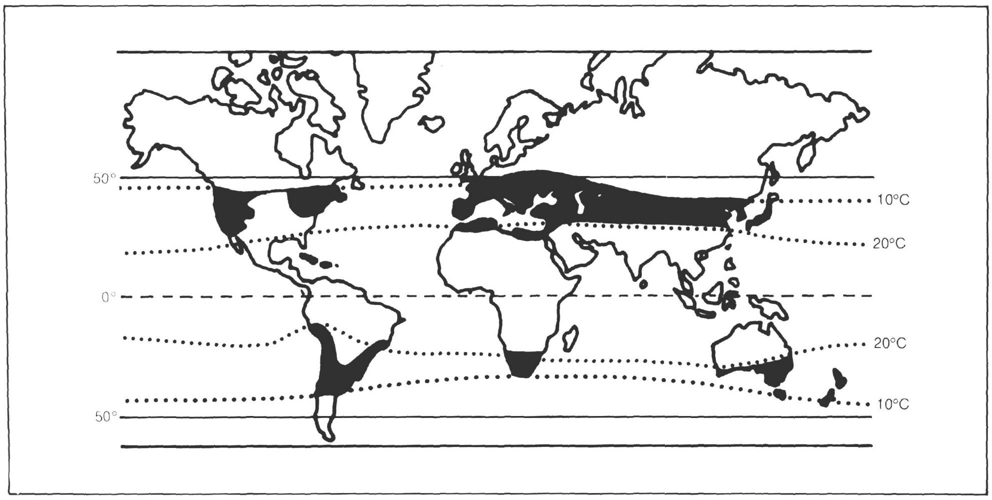

Figure 3.6: World distribution of viticulture. The dotted lines represent the mean 10^oC and 20^oC temperature boundaries. The black areas represent the “ideal” wine grape growing regions (source: Jackson and Schuster, 1997).

Hot temperatures/heat damage

As temperatures rise during the growing season berries become more susceptible to sunburn. Most susceptible are berries that have developed in shaded regions of the vine. Berries exposed from their early development are more resistant but even these can be damaged as temperatures rise above 32°C. Damage can be in the form of light sunburn which does not kill any part of the berry. Such fruit may contain slightly higher quantities of tannins which can impair the fruit quality. More serious damage can kill the whole berry, and sometimes at least half the bunch can be destroyed (Jackson, 1997).

Cold temperatures

The length of the frost-free period is also important. The frost-free period is defined as the average number of days between the last frost of winter and/or spring and the first frost of autumn. It is known as the growing season. The minimum number of frost free days required for productive viticulture is 180. Low temperatures have the ability to cause damage and injury in plants, and a plants tolerance to low temperatures depends on its stage of development. In spring, as buds swell, their susceptibility to cold damage increases. Therefore, a bud that can survive –15 ^{o}C in the middle of winter, will have its resistance lowered to 1-2 ^{o}C at bud burst. From the time of bud burst, temperatures below –1^{o}C damage buds, leaves and fruit. In the spring, frost kills emerging buds and their shoots, as well as any developing fruit. New growth will result after the damage has occurred, but the secondary shoots are much less productive than the primary shoots and maturity will be delayed due to grapes ripening later in the season. Early winter frosts will kill leaves and the remaining fruit will have to carry out their growth without the carbohydrates supplied from those leaves. Serious frost events will severely damage the fruit (Jackson, 2001). Below is a more in-depth description of frost and its impact.

3.5.2 Frost

Definition

A frost event is defined as the condition that is present when air temperature near the Earth's surface is at or below zero degrees Celsius (Aron, *et al* 1971). There are two forms of frost: white frost and black frost. A white frost is caused by the sublimation of ice crystals on exposed surfaces. The exposed surfaces must be at a temperature below freezing. A black frost is when the air temperature is below $0^{o}C$, and the air does not contain enough moisture to produce any visible sign of white ice appearing on exposed surfaces (Rosenberg, 1974). Black frosts are not common in New Zealand (Hewett, 1971).

Frost may also be defined, based on its origin, as advective and radiative. Advective frost results from the advection of cold air, and is characterised by strong winds under the control of synoptic scale weather patterns. The cold conditions can last for days. Advective frosts very rarely occur in New Zealand (Caprio et al, 1992). A radiative frost occurs when the ground cools through radiation on cold, calm and clear winter nights. This type of frost occurs when there are light winds and a temperature inversion is normally present (Figure 2.6). The spatial distribution of radiative frosts tends to vary locally. For example, cold air is inclined to flow into hollows and the bottom of valleys, while the higher slopes can encounter elevated temperatures (Sturman and Tapper, 2001).

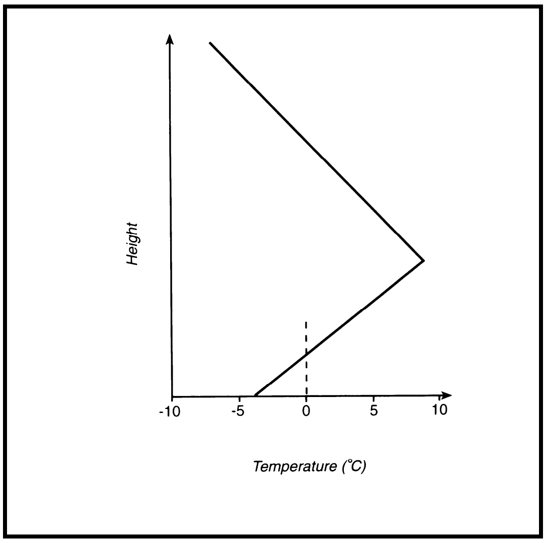

Figure 3.7: Radiation-induced temperature inversion, with a region of sub-zero temperatures nearer the ground and a layer of warmer air above (source: Sturman and Tapper, 2001).

Factors affecting radiative frost development

Hewett (1971) stated that there are a number of factors affecting radiative frost development. These are as follows:

- Season
- Cold airflow
- Clouds
- Water vapour and humidity
- Aspect
- Heat flow in the soil
- Effect of vegetation cover

Season

Frosts are common in winter due to the short days and the long nights. This is due to the inability of the soil to store enough heat from the sun during the day. During spring and autumn, the soil is still unable to store enough heat to prevent frosts, and the heat that it has stored during daytime is lost as longwave radiation during the long nights (Hewett, 1971).

Cold airflow

Cold, dense air flows from mountain ranges and hillsides into the valleys and the plains under the influence of gravity. This cold air has a tendency to pool in hollows and the bottoms of valleys, which are therefore particularly frost prone.

Clouds

Frost development is affected by clouds. The presence of low cloud or thick layers of fog will prevent frosts. This is due to the water vapour present in clouds acting as a shield to outgoing radiation. The clouds absorb the radiation and re-emit it back towards the surface, therefore reducing the radiation loss (Hewett, 1971).

Water vapour and humidity

Radiation heat loss is partially regulated by the quantity of moisture in the atmosphere. The dew point is the temperature to which the air must be cooled to form dew. Dew will form when the dew point is above $0^{o}C$, but when the temperature drops below $0^{o}C$ ice crystals will form on exposed surfaces (Hewett, 1971).

Heat flow in the soil

The condition of the soil affects the amount of heat lost from it at night. Loosely cultivated soil has many air spaces that trap air and because trapped air is a good insulator it therefore prevents heat loss. Compacted soil allows heat to escape easily from its surface. Therefore, when soil is compacted the air directly above the surface can be between 2-$4^{o}C$ warmer than that above loosely compacted soil (Hewett, 1971).

Vegetation cover

Frost severity is affected by the presence of vegetation cover. The vegetation acts as an insulating layer at the surface, preventing heat flow into the surface during the day and heat flow out of the surface at night (Figure 3.8).

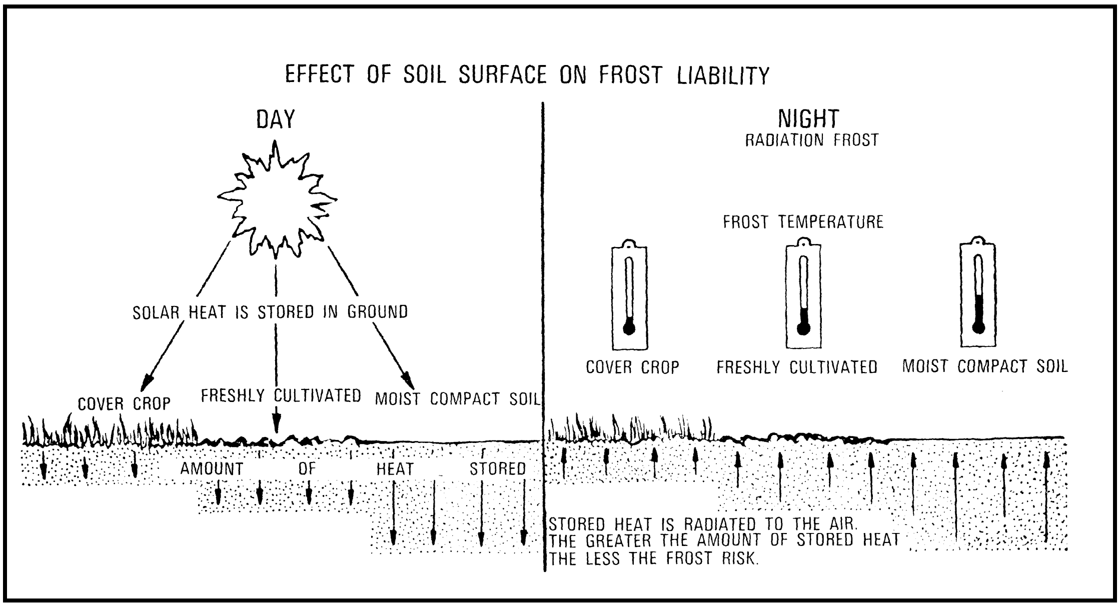

Figure 3.8: Differences of the surface and ground cover lead to changes of daytime heat storage and night radiation loss (source: Hewett, 1971).

Managing the frost risk

Oke (1987) stated that frost management solutions can fall into three categories:

1. Energy loss from the system can be retarded
2. Existing energy can be redistributed within the system
3. New sources of energy can be added to the system by artificial means.

The possible solutions are air mixing, overhead sprinkler systems, foliar sprays, artificial heat sources, soil management and crop cover selection.

3.5.2 Wind

Wind can alter the microclimate of a vineyard. The air around the grapevine heats up with the sun in the calm conditions and can be up to 10°C warmer than that of the grapevine that is exposed to a cold wind. Also in dry conditions, wind promotes transpiration; therefore the rate of the grapevine growth is slowed due to water loss (Jackson, 2001).Wind can have a very significant effect on the grapevine. For example, studies in Argentina by Simon (1977 – in Smart, 1985) show that, there can be a delay in flowering, fruit set and verasion when the grapevine is exposed to strong winds. The shoots will only reach 70% of the length of sheltered shoots, there is a 10% reduction in bunch length and yield can be reduced by at least 50%. Also increased wind speeds causes increased transpiration water use which may result in water stress.

Those vines that are grown in areas prone to wind gusts may suffer from broken shoots, the consequences of which will depend on the time of year. If they occur early in the season unusual branching patterns may occur and if it happens later in the season, crops may well be lost (Pearson and Goheen, 1988). It is recommend that the use of shelter belts provide some measure against winds as well as orientating the rows perpendicular to the mead wind direction.

3.5.3 Solar Radiation

The grapevine needs a lot of light, and the intensity and the duration of the incoming light has significant affects on the phenology of the grapevine (Galet, 2000). It can also affect the grapevines physiology in three ways: by changing tissue temperature, by photomorphogenisis, and by the supply of energy for photosynthesis. It has been shown that the grapevine canes that are exposed to the sun are more fertile then those in the shade. Also, they were overall more fruitful and had a greater number of buds present (Koblet, 1985). There have been various studies examining the correlation between light intensity and the development of grapes (Smart, 1988; Dokoozlian and Kliewer, 1996). The studies have shown that grapevines in the shade can have slower berry development, delayed onset of verasion, reduced final sugar levels and differences in acidity levels.

The total number of sunshine hours also has an effect on the grapevine. Most European vineyards do not receive anything less than 1250 hours on average during the growing season. This amount of sunshine is needed, otherwise the required heat summation for grapevine cultivation will not be met (Becker, 1977). The right amount of sunshine and warm temperatures during the start of the growing season favours berry setting within the buds.

3.5.4 Precipitation and moisture availability

Precipitation, relative humidity, evapo-transpiration, snow and hail are all factors of concern to viticulturalists. Precipitation is beneficial for grapevine growth and survival. The grapevine needs at lest 150-300mm of precipitation during winter for the accumulated moisture reserves in the soil. During budburst and harvesting, at least 250-350mm is needed to continue vegetative growth (Jackson, 2001). The timing of the precipitation is crucial. Heavy rain near to harvest can cause the berries to split and split berries are more susceptible to disease. This will not only reduce the yield, but the resulting wine quality as well. High humidity can also make the right conditions for many fungal diseases.

3.6 Summary

The environment in which a plant grows greatly affects it. It has an effect on both its growth and developmental factors. The climatic conditions will impact on the plant at both the marco- and meso-scales. The grapevine is one of the most environmental sensitive plants. The quantity and quality of the wine produced is greatly influenced by the prevailing climate. Therefore, the study of the grapevines phenology is very important. It is essential in the management of a vineyard. Providing the viticulturist with the necessary information on his/her vines. Understanding the structure and annual growth cycle of the grapevine is an important part of this. Also an understanding of what climatic factors influence and/or affect its development and how affect is very important.

Chapter 4

Cool Climate Viticulture

4.1 Introduction

Climate is one of the most important factors influencing where grapes are grown and the quality of the wine produced from those grapes. The regions where grapes are grown can be classified depending on their climate. The regions can be considered as either a warm climate or a cool climate. The definition of a cool climate is that "a grape is growing in a cool climate when the mean temperature in the month before harvest is 15^{o}C or below" (Jackson, 2001, pp 5). In regions classified as cool, grapes ripen just before winter sets in. Examples of regions that are classified as cool climates are in France north of Bordeaux, Germany, western American districts north of California, parts of South Australia and New Zealand.

Cool climates are characterised by lower temperatures in autumn, which when in combination with considerable diurnal temperature variations lead to the slowing of development. This means that there are better balances between sugar, acid and pH levels, and more aromatic and flavour constituents are accumulated, so that overall the best quality table wines are produced (Jackson and Schuster, 1997).

Figure 3.5 shows where the majority of wine is produced around the world. This occurs mainly between the latitudes of 30^o to 50^o, which more or less equates to mean annual temperatures of 10^oC and 20^oC (Jackson, 2001). If the mean temperature is below 10^0C, it means that the winters have the potential to be harsh and the summers will be short. With short summers, grapes have less time to ripen and cold winters can damage and/or kill the vines. However, if the mean temperature is above 20^0C, it means that the winters will be mild and leaf fall and vine dormancy will either not occur or only partially occur. Temperate plants like vines will therefore grow poorly. The highest quality wines produced are within the mean 10^oC and 20^oC temperature limits. It is also known that wines produced near the cooler limit are usually of very high quality (Jackson and Schuster, 1997).

Grapes grown in cool climates have a number of characteristics. For example, there is a considerable variability between the qualities of the vintages depending on the season. This is because when temperatures are cooler than average conditions, the less ripe the grapes become. Yields tend to be lower than grape varieties in warmer climates. The grapes also have lower sugar content and in the cooler seasons, the acid levels can be too high. Also, cool climate wines are considered to be more delicate and elegant, and the higher acids give a sense of freshness to the wine. In general, white wines tend to be more successful in cool climates (Jackson and Schuster, 1997). Cool climate regions have the potential to be susceptible to frost. Frost may damage the crop in spring or autumn and in cold summers, grapes may not ripen properly. Nevertheless, winemaking in a cool climate is economically viable because in the better years, the quality is excellent and high prices can be achieved (Jackson, 2001).

4.2 Climate Indices

It is a common process to relate a wine-grape classification system to a devised climatic index. Over the last 100 years or so there has been a number of climatic indices devised, containing various variables. The overall objective of an index is to produce a standard which can be used to locate potential grape growing areas worldwide. Climatic indices can be very useful for vineyard management. They have two main uses. Firstly, they can indicate climatic variations within seasons for a specific region for either one year or through a comparison between years. Secondly, they can determine the viticultural potential of a new area, as well as determining which grape varieties would be best suited to the climatic environment.

4.2.1 Degree-Day heat summation system

The most widely used climatic and best known system has been the sums of heat (temperature), commonly referred to as degree-days (or heat units) over a specific period of time, which is commonly reflected by phenological stages. The equation is shown below:

Degree-day (DD) = (Tm – Tt) x X

Where Tm is the mean monthly temperature, Tt is the pre-defined base temperature level and X the number of days in the month.

The degree-day concept was first developed by de Candolle in 1855. He defined that the annual minimum of 2,900 degree-day centigrade (DD) above a threshold temperature of 10ºC was required for grape cultivation (Prescott, 1969). The base temperature of 10ºC is used due to insignificant vine growth occurring below this temperature. The continuing development of this system was undertaken by de Gasparin in 1860, who then classified the most popular vine varieties into seven groups according to their full maturity date and assigned values of total heat quantities for each group.

Amerine and Winkler (1944) carried out one of the most well-known studies of the correlation between the sums of temperature and vine phenology. From the principal grape growing regions of California, they evaluated the influence of the climatic environment on the differing grape varieties. They achieved this by separating the grape districts into five climatic regions based on the DD system, using a base threshold temperature of 50ºF (10ºC) for the period 1st of April to 31st of October. The regions are defined as below (using DD format):

Region I = Cool – below 1390

Region II = 1390 - 1667

Region III = 1667 - 1945

Region IV = 1945 - 2220

Region V = Very hot – above 2220

The DD system was used because it was found that previous methods did not define the effects of climate well enough for the purpose of wine-producing grapes. In California, each of the grape growing regions was placed in one of the categories according to its DD evaluation. Amerine and Winkler (1944) provided a broad description of the types of grapevine varieties that can be grown and the styles of wine that could be produced from each of the five categories. This was later revised by Winkler et al (1974). Figure 4.1 shows the locations of each classified region in California based on the DD summation system above 50ºF.

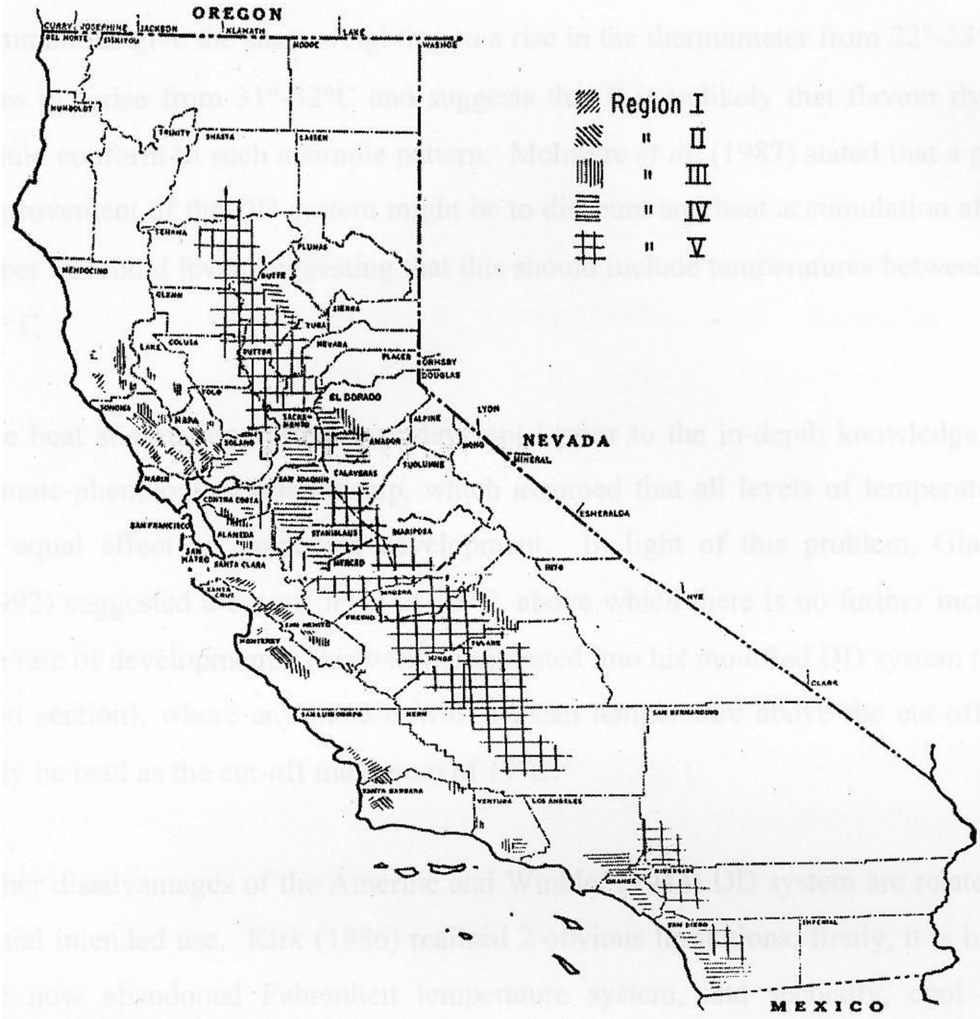

Figure 4.1: The climate regions of California based on the heat summation above 50ºF (10ºC) (source: Winkler et al, 1974)

4.2.2 The Mean Temperature of the Warmest Month (MTWM)

Prescott (1969) found that the mean temperature of the warmest month (MTWM) of the growing season could be used to establish the geographical cool limit of viticulture, which has proved to be 18.7 ºC. The MTWM is simply calculated as the temperature of the warmest month in the growing season. Coombe and Dry (1988; 1989) have also used the MTWM (which is normally January in the Southern Hemisphere and July in the Northern Hemisphere) to indicate climatic zones. They have found that this index works well within

Australia, as it does not require any complex calculations or the searching out of less accessible data. However, it does not translate well when comparing climatic zones of differing areas. Also, it is not able to be used for the comparison of seasons.

4.2.3 The Latitude Temperature Index (LTI)

The length of the growing season is very reliant on latitude. It has even been put forward that it is a better indicator of climatic suitability than the Degree Day system. The LTI was developed in New Zealand at Lincoln University. This index uses two parameters, MTWM and latitude. The equation is as follows:

LTI = MTWM x (60 – latitude)

Jackson (2001) has stated that the LTI is better for comparing to ripening capacity of a district than the use of degree days, especially for discriminating between cool climate areas.

4.3 Grape Varieties

The grapes that are best suited for cool climates are Cabernet Sauvignon, Chardonnay, Chasselas, Chenin Blanc, Gewurztraminer, Kerner, Malbec, Merlot, Meuniere, Muller-Thurgau, Muscat Ottonel, Pinot Blanc, Pinot Gris, Pinot Noir, Riesling, Sauvignon Blanc, Semillon and Sylvaner (Jackson and Schuster, 2001). The grape varieties that are described in full below are the main varieties that are grown in the Waipara area.

Cabernet Sauvignon

Cabernet Sauvignon originated from the Bordeaux region in France (Antcliff and Kerridge, 1999). On the whole, it is the most prevalent red wine grape after Merlot. It has a rather upright growing habitat with flexible shoots. It is acknowledged as a highly adaptable grape variety (Galet, 2002). In cool climates like Canterbury, it tends to ripen late in the season so it has to be grown in favoured locations (Jackson *et al*, 2002). However, in very cool climates it will not ripen at all. It generally has small to medium yields of grapes, but the high quality of wine more often than not compensates for the lower yields. It suits most soils, but has a high susceptibility to the disease powdery mildew and low susceptibility to bunch rot and botrytis. It has a reasonably late bud burst, so that it is in little danger from springtime frosts. At harvest time, the grapes are large enough to withstand wet weather which can cause rot (Jackson and Schuster, 2001).

Chardonnay

There is not a wine region in the world that does not have plantings of Chardonnay (Galet, 2002). It has a yellow-green grape that is not suited to heavy clay loams, but is more suited to the well-drained fertile and drier calcareous soils. Chardonnay has a moderate susceptibility to powdery mildew and a moderate to high susceptibility to bunch rot and botrytis (Jackson and Schuster, 2001). It is particularly open to damage from spring frosts, while heavy rainfall during development can increase risk of the fruit not setting (Galet, 2002).

Gewürztraminer

Gewürztraminer is originally from the Italian Tyrol and was first seen in Alsace in the 16th century. Gewürz means spicy. It is also known as Sauvignon Rose and Traminer. It ripens early and is susceptible to frosts (Galet, 2002). It gives grapes that can be both pink and white in the same bunch. The grape yields tend to be low to moderate. It does best in and prefers deep and fertile soils. It has a high susceptibility to powdery mildew, bunch rot and botrytis. During ripening and flowering, wet weather can cause poor bunch set and spitting of the berries (Jackson and Schuster, 2001).

Riesling

Germany is considered the home of Riesling, where it is the most planted white grape variety. It needs to be planted in northern facing vineyards that are very sunny (Galet, 2002). It has a late bud burst and usually ripens late in cooler areas. The overall quality and quantity of the resulting grapes depends greatly on the appropriateness of the soil type. The best wine is produced in lighter, well-drained, warm soils of either stony alluvial or volcanic origins with good balances of the nutrients potassium and magnesium. It has a fair susceptibility to powdery mildew. It has a high susceptibility to bunch rot and botrytis, and tends to have lower grape yields although the newer clones have given moderate to high yields (Jackson and Schuster, 2001).

Pinot Noir

Pinot noir is known for the fine red wines of burgundy. It can be reasonably temperamental and is sensitive to diseases. It also has a tendency to ripen early. It prefers well-drained deeper soils. It has fair susceptibility to powdery mildew and fair to high susceptibility to bunch rot and botrytis, but is fairly resistant to wet weather. The grape yields are low to moderate (Jackson and Schuster, 2001).

Sauvignon Blanc

Sauvignon Blanc prefers gravely soils or sandy loams. It does not do well in very dry or calcareous soils. Also, it does not do well in deep fertile soils due to it causing excessive growth and poor crops, making the berries more prone to rot. It has a fair to high susceptibility to powdery mildew. It has high susceptibility to bunch rot and botrytis. It has poor resistance to wet weather. The grape yield is usually low to moderate depending largely on the area it is grown within and the training of the vines. The grape tends to ripen late in the growing season with fair acidity and occasionally with high sugar content. The best examples of Sauvignon are the wines of New Zealand (Jackson and Schuster, 2001).

4.4 Summary

The climate plays a major role in the placement of vineyards and the choices made when deciding what varieties will be grown there. Grapes grown in cool climates produce larger yields; have lower sugar content and higher acid levels, resulting in a high quality table wine. White wines are more successful in the cool climates. With the cool climates comes a susceptibility to frost. These frosts can damage the crops so the grapes may not ripen properly. With such differing climates globally, a climatic index was developed, with the aim being to produce a standard where the potential grape growing areas can be identified. These can also be used in the management of the vineyard, indicating the seasonal climatic variations, the determination of potential areas and what varieties can be grown. The most widely climatic system used is Degree Days over a stated period of time, which is reflected by the phenological stages of the plant. Other systems used are WTWM and LTI. These both have been limited in their widespread use for differing reasons.

Chapter 5

Research Methodology

5.1 Introduction

Knowledge of the climatic setting is important background information, which is vital to interpreting the data analysed in this study. The methodological procedures used throughout this research will therefore now be discussed. How the data were collected, evaluated and presented will be described. The study area is first described, and the climatic setting explained. This is then followed by a description of the methods of field based data collection. An outline of the methods used to convert the raw climatic data into readable maps and graphs will be provided in the following sections. The limitations of the techniques used will also be discussed.

5.2 Background

New Zealand's climate is influenced by mid-latitude synoptic weather systems, and there is a dominance of westerly winds. This is due to a steep latitudinal thermal gradient, which produces a strong thermal wind (Sturman and Tapper, 1996). Fronts, depressions and anticyclones are prevalent over New Zealand. They form due to the interaction of cold polar air and subtropical warm air. The climate of New Zealand is multi-faceted and varies from warm subtropical conditions in the far north to cool temperate climates in the south, as well as severe alpine conditions in the mountainous areas (NIWA, 2000).

New Zealand's weather is affected by a series of depressions followed by anticyclones moving eastwards across the region. Troughs from northwards depressions extend from the south of New Zealand. They generally move eastwards over the country. Cold fronts are often located within these troughs, orientated northwest to southeast. Warm, moist air is brought by the northerly winds within the depressions. When the depression shifts east, there is a change in wind direction and the country is flooded by cold southerlies. The weather that is associated with the depression (wet and cloudy) disappears and is replaced by the weather associated with anticyclones (clear, calm and cold), especially in inland regions. The centres of these anticyclones generally track easterly across the North Island, more northerly paths being followed in spring, and southerly paths in autumn and winter (Metservice, 2004). Frosts may occur in winter, spring and autumn, and when there is snow lying on the surrounding mountains the possibility of frost occurrence is increased (Hewett, 1971).

The presence of a mountain chain extending the length of New Zealand provides a barrier for the prevailing westerly winds, dividing the country into dramatically different climate regions, which produces much more apparent climatic contrasts from west to east, than from north to south (NIWA, 2004). In the South Island, the process of orographic forcing of the westerly winds by the Southern Alps results in precipitation falling on the West Coast and the east coast experiencing a warm north-westerly foehn wind (Sturman and Tapper, 1996). Due to this process, the West Coast of the South Island is the wettest area of New Zealand, whereas the area to the east of the mountains, just over 100 km away, is the driest.

Annual rainfall across New Zealand ranges between 600 and more than 10,000mm. For some of the southern areas, winter is the season of least rainfall. However, in the northern and central areas of New Zealand more rainfall tends to fall in winter than in summer (NIWA).

Mean annual temperatures range from 10°C in the south of the South Island to 16°C in the far north. January and February are the warmest months of the year, and July is the usually the coldest. The highest temperatures are normally recorded east of the main ranges, where they can exceed 30^{o}C on a few afternoons during most summers. The annual range of mean temperature (the difference between the mean temperature of the warmest and coldest months) is small, although inland and to the east of the ranges the variation is greater (up to 14°C). Temperatures also drop by about 0.7°C per 100 m of altitude (NIWA).

5.2.1 The Canterbury Region

The Canterbury climate is controlled by the effects of the Southern Alps on the prevailing westerly airflow. The plains experience low rainfall and a large annual temperature range due to prevailing winds from the northeast and southwest. The eastern foothills encounter wetter and cooler weather, and a high incidence of north-westerlies. Rainfall is low in inland basins and sheltered valleys. They also experience large ranges of annual and diurnal temperatures (Ryan, 1987). During summer, temperatures tend to be warm, with highest values occurring during hot dry north-westerlies. Mean annual rainfall is low, and long dry spells occur during summer. Summer temperatures are usually moderated by a cool north-easterly sea breeze. Daytime summer maximum air temperatures usually range from 18°C to 26°C, but on occasion can rise above 30°C. The highest temperature recorded in Christchurch was 42°C. Winters in Canterbury are cold with frosts occurring frequently. Daytime winter maximum air temperatures can range from 7°C to 14°C. Along the coast, north easterlies prevail for much of the year and south westerlies tend to be more frequent during winter (NIWA).

Canterbury's climate is moderated by the regions closeness to the Pacific Ocean and the region is considered to have "cool climate". The heat summation or degree days (defined in

Chapter 3) ranges between 800-1100, which places Canterbury at the cool end of the range of climates suitable for viticulture. The climate in Canterbury can be considered the equivalent to other well known wine growing regions around the world, such as the Moselle and parts of the Rhine Valley in Germany, the Loire Valley, Champagne and Alsace areas in France and Tasmania. The low heat summation is compensated for by the latitude of the region, which provides for greater light intensity and day length during the growing season. This allows most grape varieties to ripen sufficiently well. However, Canterbury is limited to growing grape varieties that have a relatively short growing season (Jackson, et al 2002).

5.2.2 Waipara Basin

The climate of Waipara consists of long, dry summers, abundant sunshine and relatively cool growing conditions. Waipara is located nine kilometres from the coast, but is sheltered from the cool easterly/north-easterly winds by the Teviotdale Hills that reach a height of 500 metres above sea level at Mt Cass. This shelter is a key aspect of Waipara's grape growing environment, as well as the fact that it usually makes the area significantly warmer than the rest of the Canterbury Region and regularly makes Waipara one of the warmest spots in New Zealand. The hills also limit inland penetration of the land-sea breeze. Frost can be a problem in some areas, especially on the flats, while most of the rainfall occurs in the winter and early spring.

The heat accumulated in Waipara is significantly more than that of the Canterbury Plains due to the coastal hills reducing the cooling effect of the north-easterly winds. The growing degree days can be more than 1000, and are usually higher than that found typically on the plains. The temperatures recorded in Waipara are often similar to those of the Marlborough district, and irrigation is usually required in most vineyards in the area. There are a greater number of grape varieties grown in Waipara than on the plains due to the warmer temperatures, with Riesling and Cabernet Sauvignon doing particularly well.

5.3 Study site

This study involves areas analysis at two spatial scales, the larger of which covers the whole Waipara Basin, situated on the central eastern side of the South Island within the region of Canterbury, at approximately 171°00'E, 43°S. Figure 5.1 shows the study area, and the vineyards that have supplied temperature data. The Mackenzie vineyard is located on McKenzie Road in the Waipara Village (Figure 5.2), provides the focus of a more detailed study. The vineyard supplies grapes for the Torlesse Wines winery which takes its name from Mount Torlesse and the Torlesse Mountain range. The Blowers, Fabris, Pharis, Rayner and Tomlin families own the company. The managing director and winemaker is Kym Rayner (New Zealand Wine and Grape Industry (b)). The wines that are produced by Torlesse Wines are Riesling, Gewurztraminer, Sauvignon Blanc, Chardonnay, Cabernet Sauvignon, Pinot Noir and Pinot Gris.

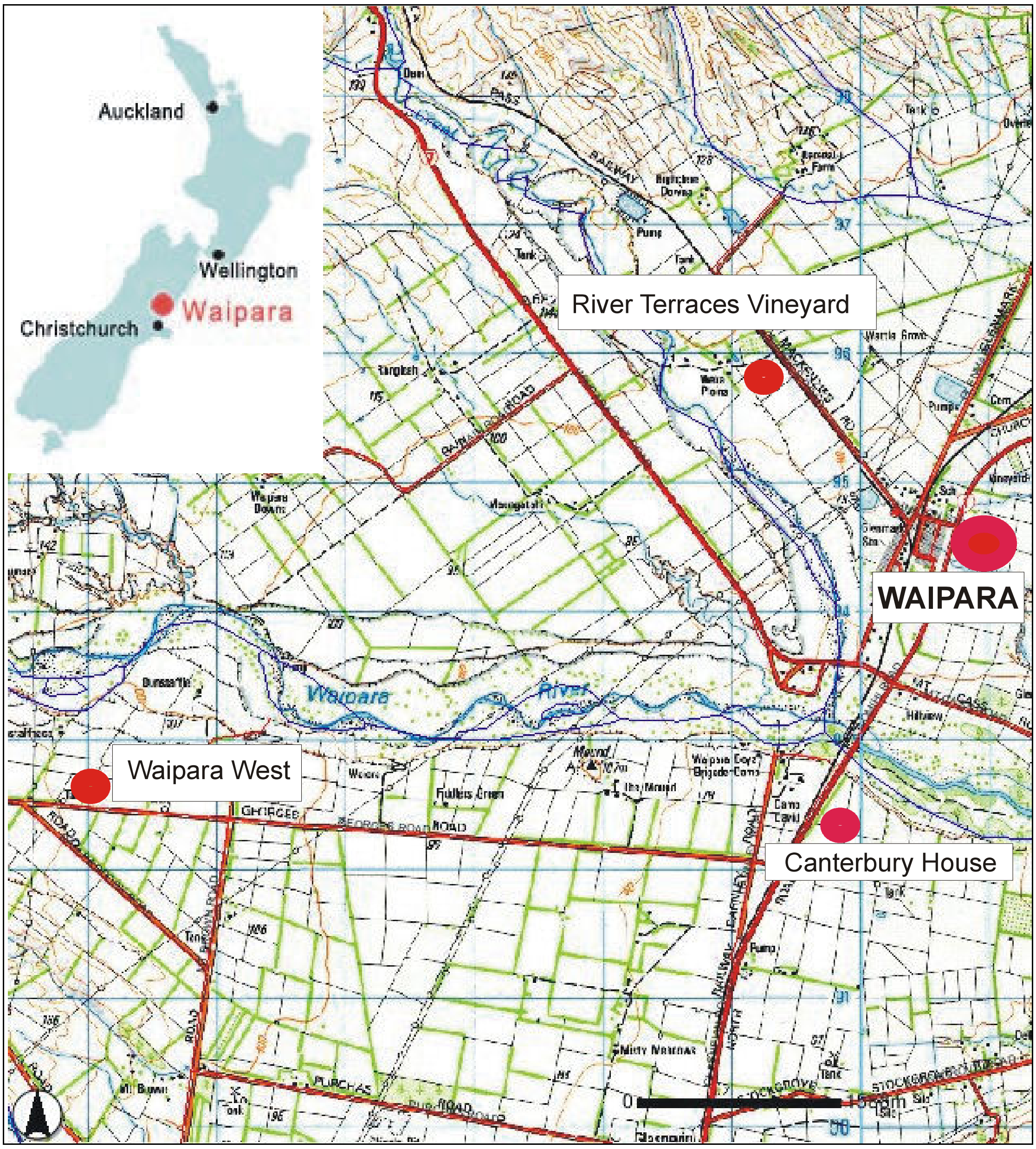

Figure 5.1: Location map of the Waipara Basin showing the vineyards that are involved in this study.

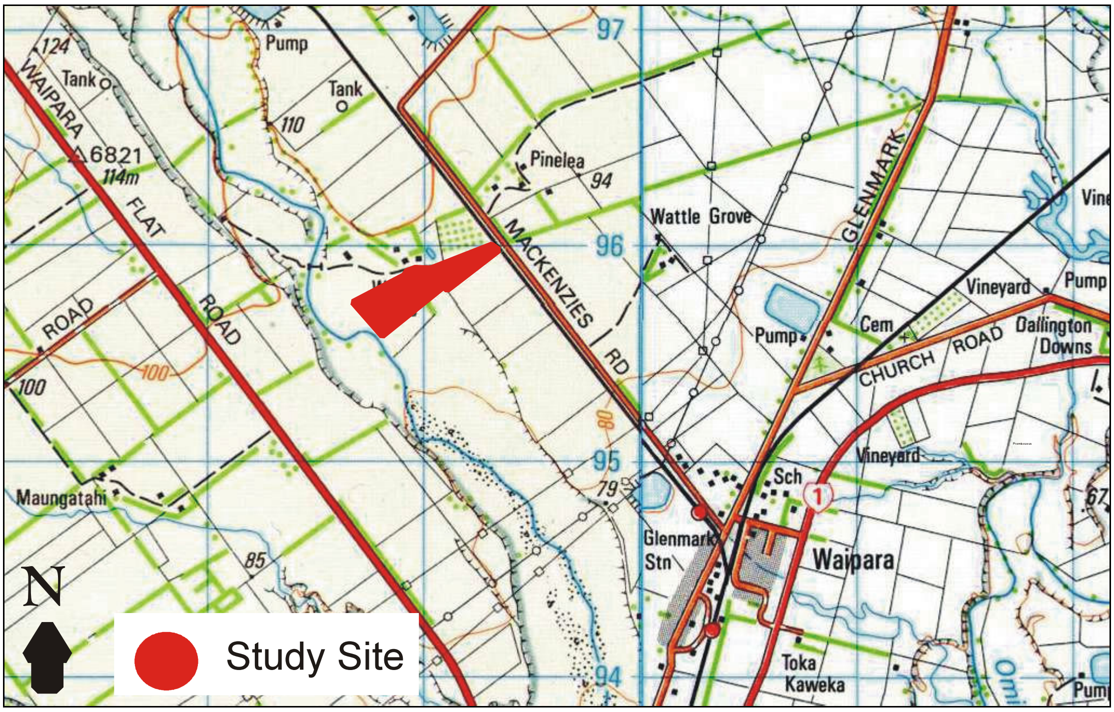

Figure 5.2: Location of the study site at the Mackenzie vineyard, Waipara.

The McKenzie vineyard is 19 hectares in size. The topography consists of upper and lower terraces that are separated by a 5m high terrace edge. Both terraces are reasonably flat, with the lower terrace being more undulating (figure 5.3 and 5.4). The upper terrace is larger in size than the lower terrace.

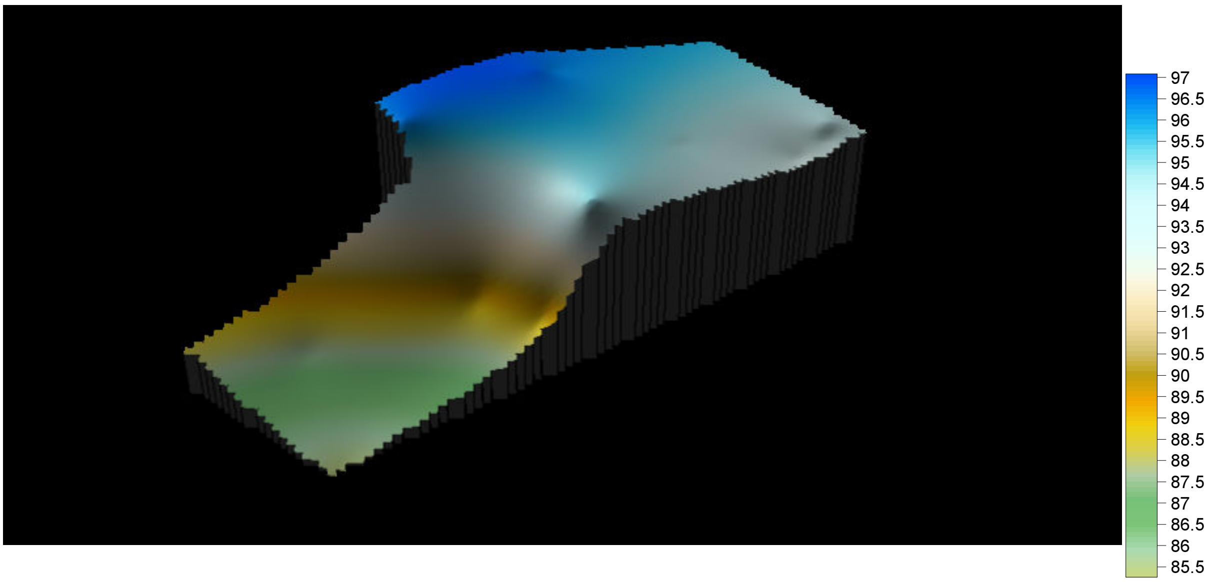

Figure 5.3: Elevation map

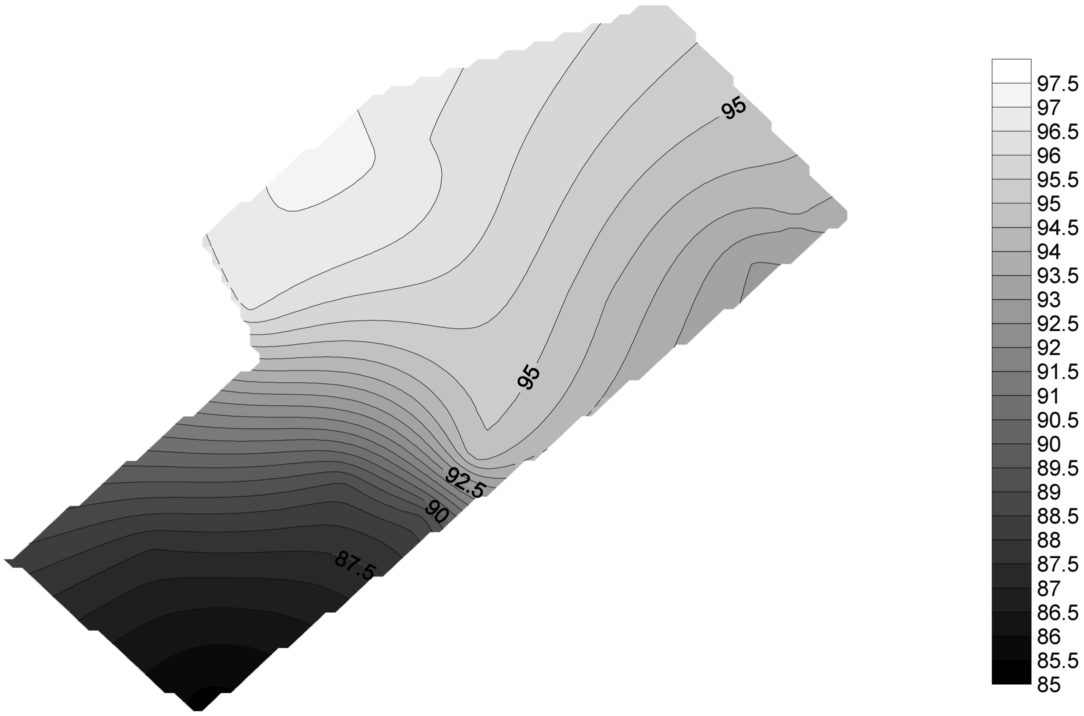

Figure 5.4: Elevation contour map

5.4 Methodology

This study has employed a number of techniques to address the main objectives outlined in Chapter 1. Temperature data collected from sixteen temperature loggers (HOBO's) and an Automatic Weather Station (AWS) located within the Mackenzie vineyard was imported into an Excel database for analysis. Temperature data collected from other vineyards were also imported into an Excel database together with the grapevine development observations. The monthly mean, maximum and minimum temperatures were derived for each of the vineyards while the number of Degree Days (DD), the Latitudal Temperature Index (LTI) and the Mean Temperature of the Warmest Month (MTWM) was interpolated for each vineyard. An outline of the methods used to convert the collected climatic data into maps and graphs will be provided in the following sections.

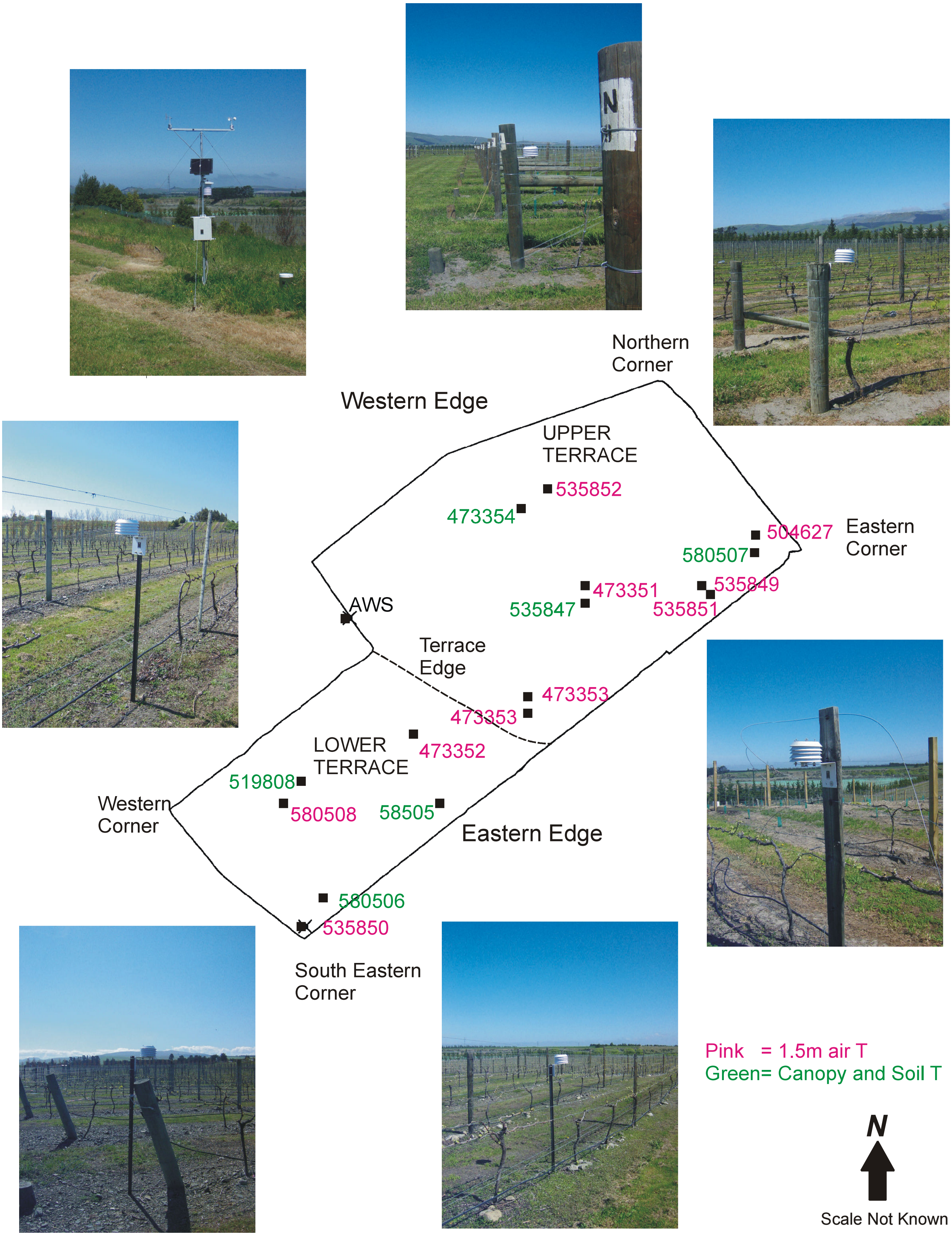

Figure 5.3 : Distribution of the temperature sensors around the Vineyard

Figure 5.3 Locations of the HOBO temperature loggers and the AWS within Mackenzie the vineyard.

5.4.1 Vineyard setup

An Automatic Weather Station (AWS) and the HOBO's was setup in various locations following discussion with by the vineyard owner. These locations can be seen on Figure 5.3

5.4.2 Data collection

The Automatic Weather Station (AWS) has been operating in the vineyard since mid-June 2003. It is located in the open, well clear of the rows of vines, and collects data at 30 minute intervals. The data consist of temperature, relative humidity, soil temperature, wind speed and direction and solar radiation, providing an overall indication of the climatic conditions experienced during the study.

There were originally six temperature loggers (HOBOs) set up within the rows of vines in the Mackenzie vineyard that have been operating sine mid June 2003. These are located at 1.5m in the vine canopy. An additional ten HOBOs were set up in the vineyard at selected locations, to provide a more comprehensive understanding of the thermal environment of the vines and to illustrate spatial variation of temperature within the vineyard. Eight of the HOBO's were set up at the height of 1.5m, while the other eight HOBOs were at grapevine height. The data collection network also includes eight sets of soil temperature sensors, at a depth of 0.5m, along selected rows of vines, as soil temperature is considered to be a major control of plant phenology, particularly during spring. The HOBOs were setup within the different grape varieties. Ten HOBOs were located on the upper terrace of the vineyard with six more located on the lower terrace of the vineyard, the HOBOs were connected to the vine row posts and the temperature was logged at 10 minute intervals.

The study periods that will be used is firstly for the larger scale study of the Waipara Basin, November 2003-November 2004.For the McKenzie vineyard the study period will be September 27th to December 29th and will be referred to throughout the following text as the growing season.

The standard height of 1.5m for location of the HOBOs was decided upon because this height has been the international standard for climate observations toward the end of 19th century. The HOBOs were located to be ‘representative’ of the temperature conditions experienced in different parts of the vineyard while the AWS was located to represent the climate of the surrounding area.

The data were downloaded from the AWS and the HOBOs through a palm pilot program called PCONNECT. The Handcar programme was used to download the data from the HOBOs. Observational measurements of plant development were obtained subjectively at weekly intervals by the vineyard manager. GPS was used to map the vineyard and the locations of the HOBOs and the AWS. Surface weather maps produced by the New Zealand Metservice were also collected.

5.4.4 Analysis

Temperature data collected from the sixteen temperature sensors (HOBO’s) and the Automatic Weather Station (AWS) located within the Mackenzie vineyard was imported into an Excel database for easier handling. From the temperature data, the monthly mean, maximum and minimum temperatures were interpolated for each of the HOBO locations.

Temperature contour maps will be created using the specialised mapping program Golden Software Surfer8 and GIS.

Temperature data collected from the Canterbury House, River Terraces and Waipara West vineyards was also imported into an excel database. From the temperature data the monthly mean, maximum and minimum temperatures were interpolated for each of the vineyards. Also the number of Degree Days (DD) and the Mean Temperature of the Warmest Month (MTWM) was interpolated for each vineyard.

Met Service weather maps are used to identify the synoptic weather patterns that occur during the field season. These will then be used to help explain the data collected by the AWS and the network of HOBO's.

The observations of plant development were written into a excel spreadsheet for ease of reading, and then were used to create a timeline of grapevine development. These measurements will be compared to the data collected from the AWS, HOBO's and the soil temperature sensors.

5.7 Summary

The purpose of this chapter has been to outline the climatic background of both the study areas and to describe each of the study areas. Data collection within the vineyard consisted of a network of HOBO temperature loggers set at the 1.5 and 1m air level and 50cm soil temperature, an Automatic Weather Station and grapevine development observations. The vineyards that supplied the temperature data for the Waipara basin was identified. Finally the data analysis consisting of various graphs tables and temperature contour maps was described.

Chapter 6

Data Analysis

6.1 Introduction

The purpose of the chapter is to present the results and data analysis. The first section shows the Waipara Basin temperature analysis. The time period of November 2003 to November 2004 was chosen due to overall unavailability of long data set from the vineyards. So for the purpose of this study only the months that all four vineyards (McKenzie vineyard, Canterbury House, River Terrace vineyard and Waipara West) had sufficient data were included. The second section focuses on the McKenzie vineyard for part of the growing season (27th September to 29th December). Temperature analysis of the 1.5m, 1m and soil temperature are presented. Grapevine development and growth data is also shown. The overall of the growing season is also presented. Lastly a case study of the most severe frost is examined.

6.2 Waipara Basin July 2003 – November 2004

6.2.1. Monthly temperature summary

The average monthly temperatures of the four vineyards were reasonably similar over the year. Figure 6.1 clearly shows that Waipara West has the warmest monthly averages. Canterbury House had the slightly cooler temperatures than that of the McKenzie vineyard and River Terraces. These two vineyards had very similar monthly averages.

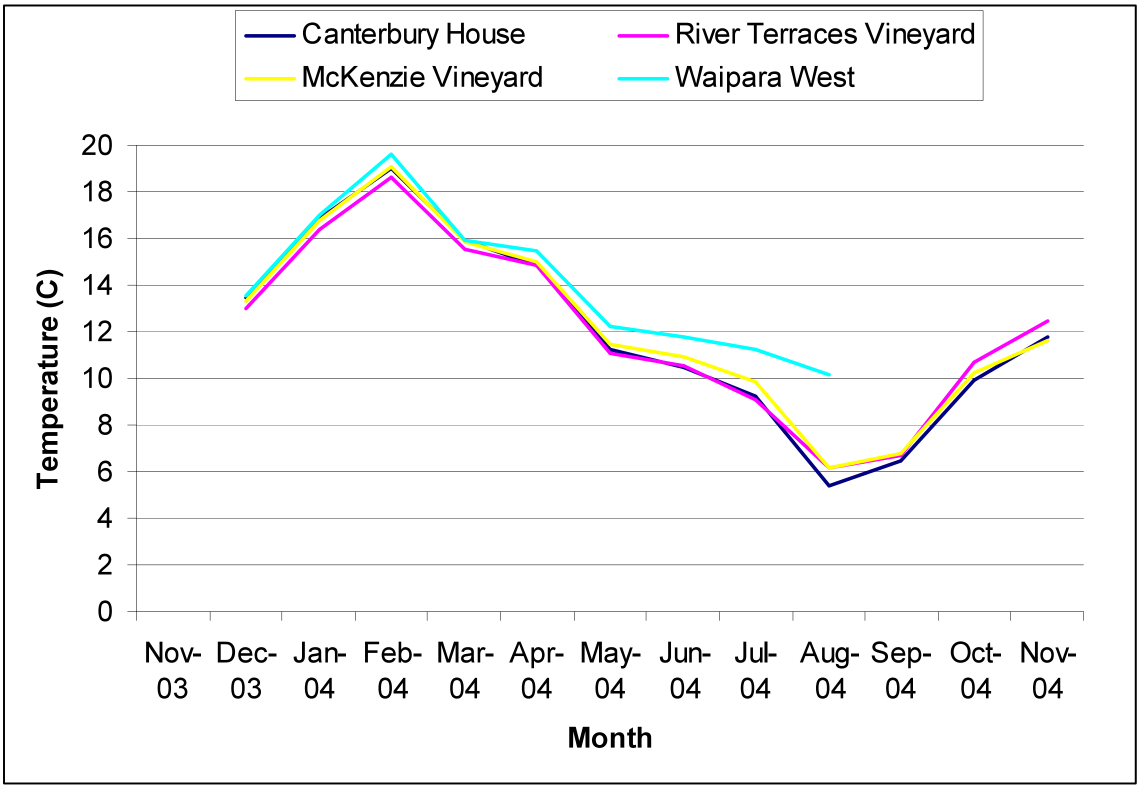

Figure 6.1: Graph showing monthly average temperature for each vineyard

Figure 6.2 shows that Waipara West recorded the highest temperature overall with 37.1 °C being recorded in January.

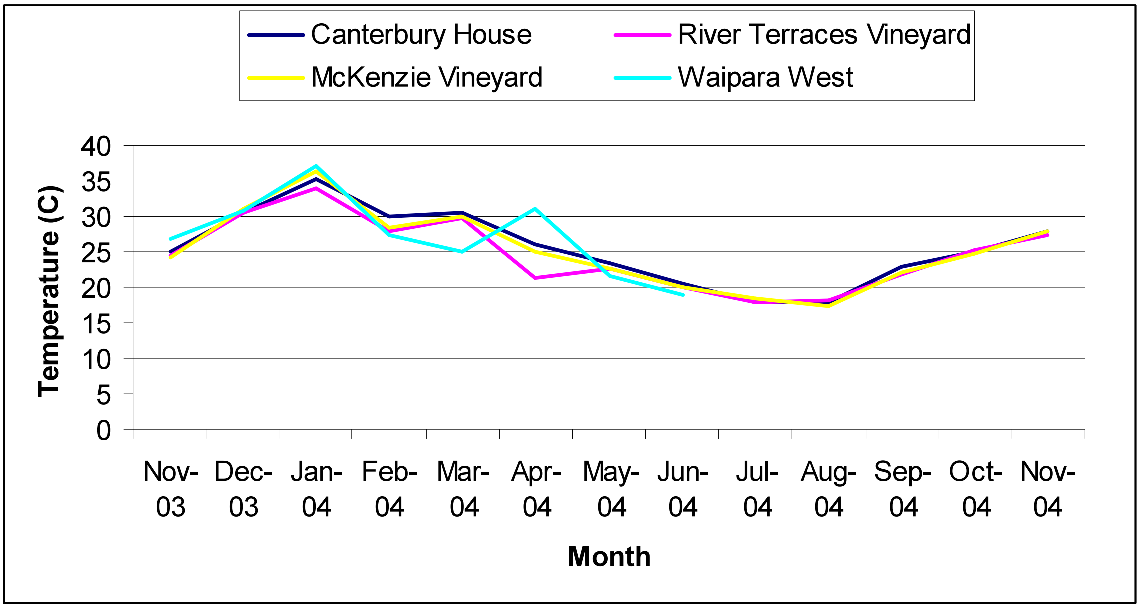

Figure 6.2: Graph showing monthly highest temperature for each vineyard

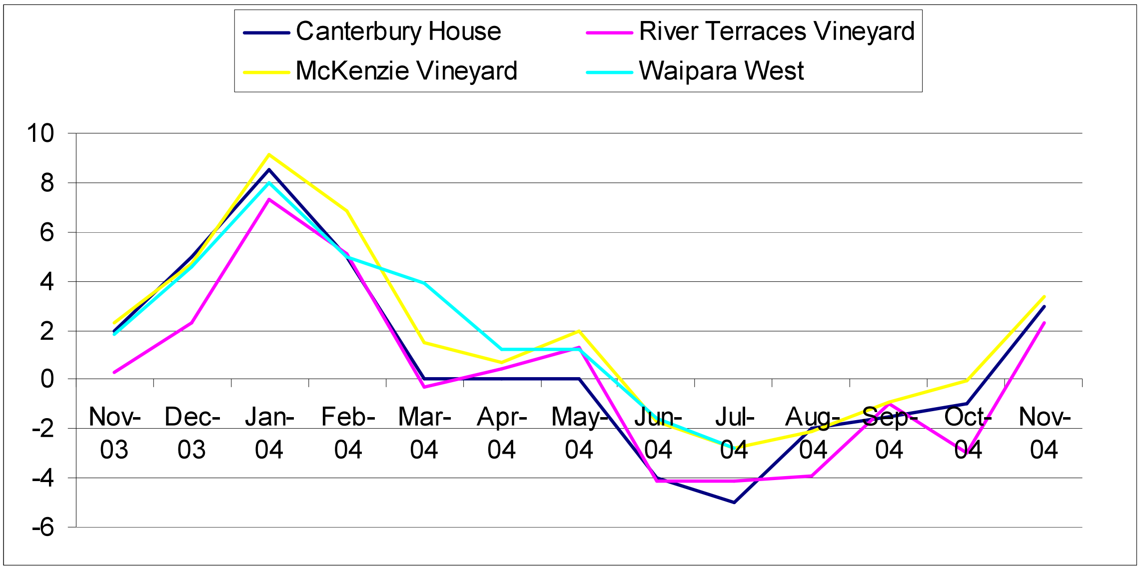

Figure 6.3: Graph showing monthly lowest temperature for each vineyard

Figure 6.3 shows that the coldest monthly temperature was recorded by Canterbury House in July with -5 C. River Terraces vineyard generally tends to have more minimum temperatures over the year with the McKenzie vineyard having slightly warmer minimum temperature then the other vineyards. Table 6.1 shows the average monthly temperatures, the maximum and minimum temperatures for each month for the vineyards involved in the study.

Table 6.1: Maximum and minimum temperatures, overall and monthly temperature average for each vineyard

	Canterbury House	River Terraces Vineyard	McKenzie Vineyard	Waipara West
Average Monthly Temps				
Nov-03	13.5	13.03	13.27	13.55
Dec-03	16.83	16.35	16.8	16.99
Jan-04	19.02	18.62	19.09	19.60
Feb-04	15.96	15.52	15.82	15.89
Mar-04	14.84	14.86	15	15.49
Apr-04	11.21	11.10	11.46	12.21
May-04	10.45	10.53	10.91	11.75
Jun-04	9.26	9.06	9.84	11.25
Jul-04	5.37	6.12	6.14	10.14
Aug-04	6.44	6.70	6.74	
Sep-04	9.91	10.70	10.22	
Oct-04	11.75	12.48	11.6	
Nov-04	15.25	14.50	15.11	
Highest temp				
Nov-03	25	24.40	24.17	26.8
Dec-03	30.5	30.40	30.93	30.71
Jan-04	35.31	34.00	36.44	37.1
Feb-04	30	27.90	28.36	27.3
Mar-04	30.5	29.80	30.01	25.1
Apr-04	26	21.30	25.08	31
May-04	23.5	22.70	22.57	21.5
Jun-04	20.5	20.1	19.99	19
Jul-04	18	18	18.49	
Aug-04	18	18.1	17.48	
Sep-04	23	21.8	22.15	
Oct-04	25	25.3	24.66	
Nov-04	28	27.5	27.84	
Lowest temp				
Nov-03	2	0.3	2.33	1.8
Dec-03	5	2.3	4.71	4.6
Jan-04	8.5	7.3	9.1	8
Feb-04	5	5.1	6.84	5
Mar-04	0	-0.3	1.5	3.9
Apr-04	0	0.4	0.7	1.2
May-04	0	1.3	2	1.2
Jun-04	-4	-4.1	-1.7	-1.6
Jul-04	-5	-4.1	-2.8	-2.8
Aug-04	-2	-3.9	-2.14	
Sep-04	-1.5	-1	-0.9	
Oct-04	-1	-3	-0.02	
Nov-04	3	2.3	3.34	

6.2.2 Degree Days

Table 6.2 shows the monthly degree days calculated for each vineyard. The total numbers of degree days are shown at the bottom of the table. Canterbury House has the highest number of overall with 1294 degree days. McKenzie vineyard has the second highest with 1192 degree days and River Terraces vineyard has total of 1149 degree days. Waipara West has the lowest number with 1064 degree days.

Table 6.2: Monthly degree days for the four vineyards

Degree Days	Canterbury House	River Terraces Vineyard	McKenzie Vineyard	Waipara West
Nov-03	108	91	98	107
Dec-03	211	197	211	210
Jan-04	279	267	282	288
Feb-04	172	160	169	177
Mar-04	151	151	150	165
Apr-04	63	33	45	66
May-04	46	17	28	52
Sep-04	34	21	7	
Oct-04	71	77	50	
Nov-04	159	135	153	
TOTAL	**1294**	**1149**	**1192**	**1064**

6.2.3 Mean Temperature of the Warmest Month

The WTWM was calculated using the mean temperature of January 2003. The resulting calculations are shown in Table 6.3. The River Terraces vineyard had the coolest MTWM with 18.62, while Waipara West had the highest with 19.60. Canterbury House and the McKenzie vineyard were very similar with 19.0n and 19.09 respectively.

Table 6.3: MTWM for the four vineyards

	Canterbury House	River Terraces Vineyard	McKenzie Vineyard	Waipara West
MTWM	19.02	18.62	19.09	19.60

6.3 McKenzie Vineyard; Growing season 27th September – 29th December 2004

6.3.1. 1.5m air temperature

The average 1.5m air temperatures over the study period only varied by 0.4°C overall between the different sensors. The maximum temperatures recorded varied by 1.32 °C and the minimum temperatures by 0.71°C overall. Table 6.1 illustrates the average, maximum and minimum temperatures taken from each HOBO as well as the monthly averages for each of the HOBOs.

Figure 6.4 shows that the upper terrace is generally slightly colder than the lower terrace. The maximum temperatures measured tend to follow the same pattern as the average temperature with the highest of the maximum temperatures being found near the centre of the lower terrace and the coolest temperatures being found at the northern end of the upper terrace (Figure 6.5). The overall minimum temperatures however did not follow the patterns described above. The lowest of the minimum temperatures were found in the bottom west corner of the lower terrace as well as low temperatures showing near the centre of the upper terrace. The eastern edge of the showed the warmest of the minimum temperatures (Figure 6.6).

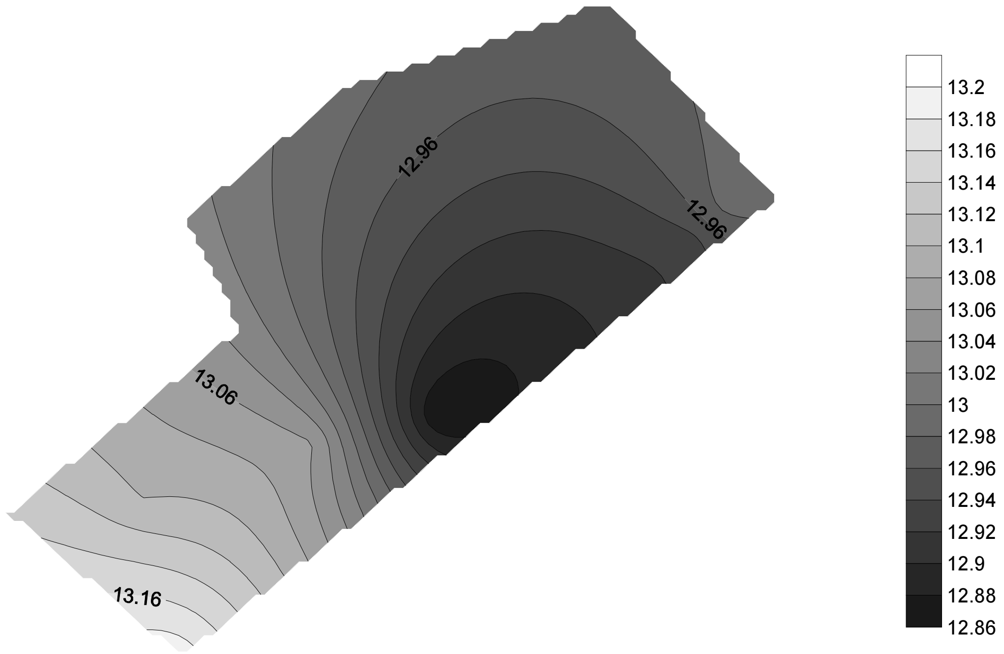

Figure 6.4: Average 1.5m air temperatures

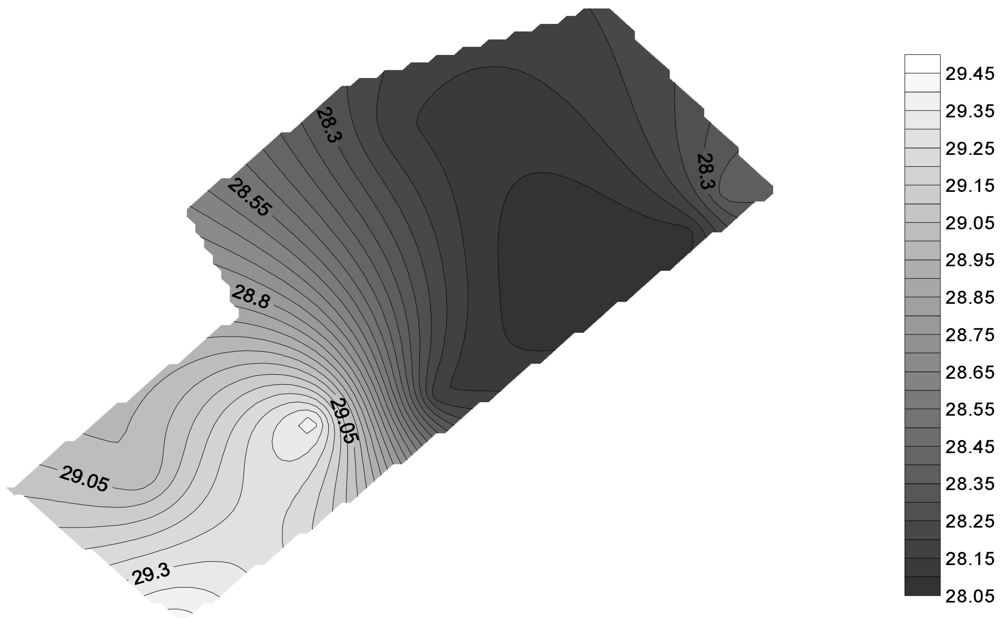

Figure 6.5: Maximum 1.5m air temperatures

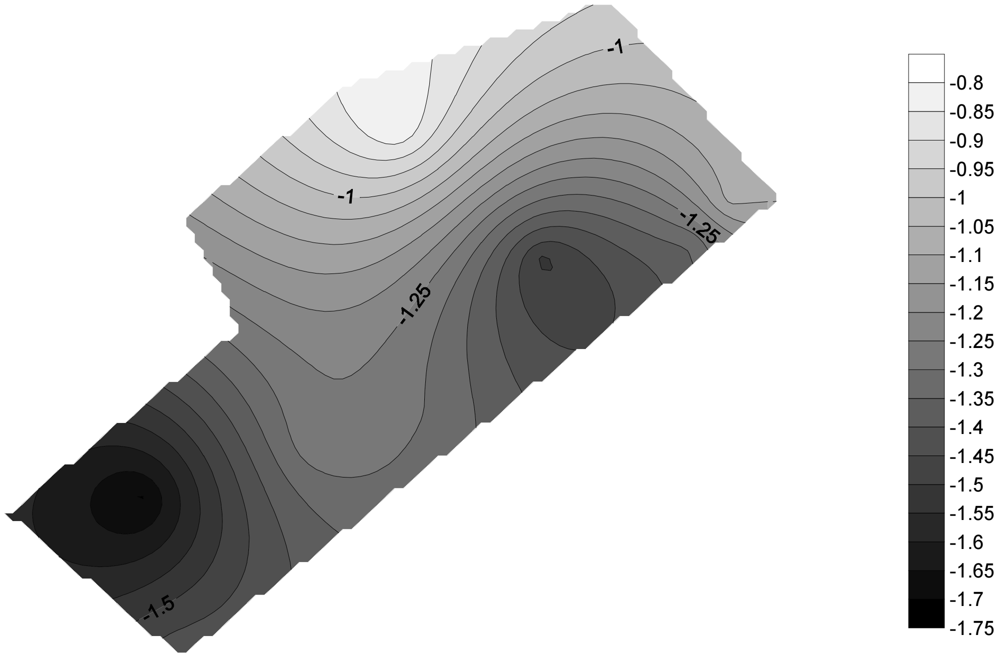

Figure 6.6: Min 1.5m air temperatures

The monthly temperature averages tend to follow the same pattern as the overall study period. The monthly averages can be seen in Table 6.3. Figures 6.7 – 6.11 show that the higher temperatures are again found in the lower terrace. Figure 6.5 clearly shows that the HOBOs on the lower terrace recorded warmer monthly averages.

Table 6.3: Maximum and minimum temperatures, overall and monthly temperature average, 1.5m air temperature for each HOBO.

	Upper Terrace				Lower Terrace		
	473351	473353	535851	535852	473352	535850	580508
Average Temp(°C)	12.91	12.86	12.93	12.97	13.06	13.2	13.1
Max temp	28.06	28.16	28.08	28.16	29.38	29.45	29
Min temp	-1.51	-1.31	-1.34	-0.8	-1.26	-1.4	-1.71
September	9.34	9.36	9.29	9.36	9.5	9.46	9.48
October	11.46	11.54	11.49	11.46	11.53	11.63	11.64
November	15.14	15.16	15.03	15.13	15.35	15.35	15.49
December	12.68	12.71	12.88	12.64	12.81	12.86	13.01

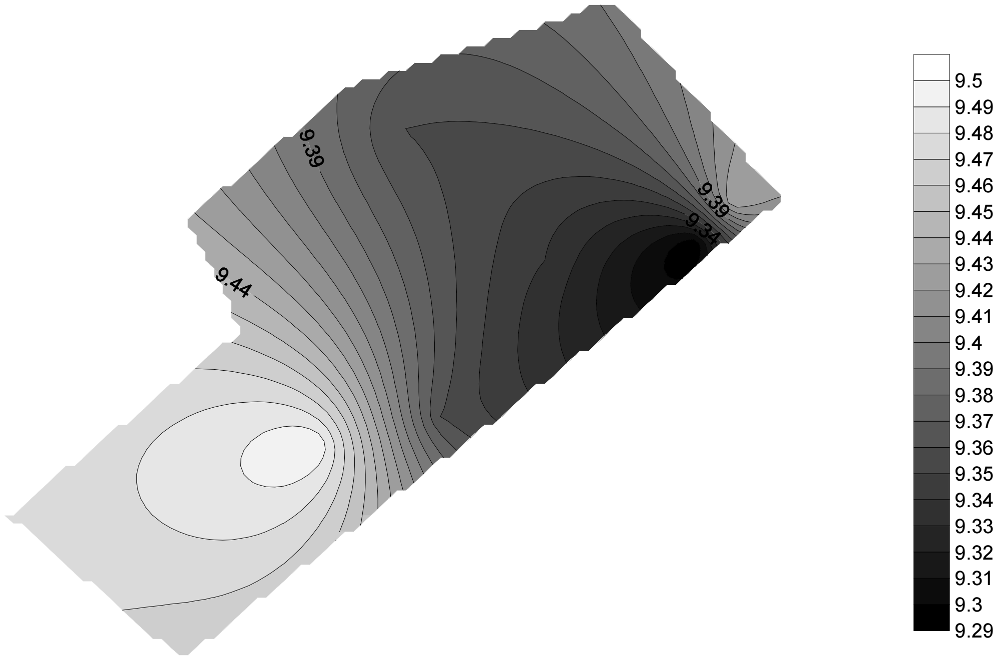

Figure 6.7: September 2004 average 1.5m air temperature

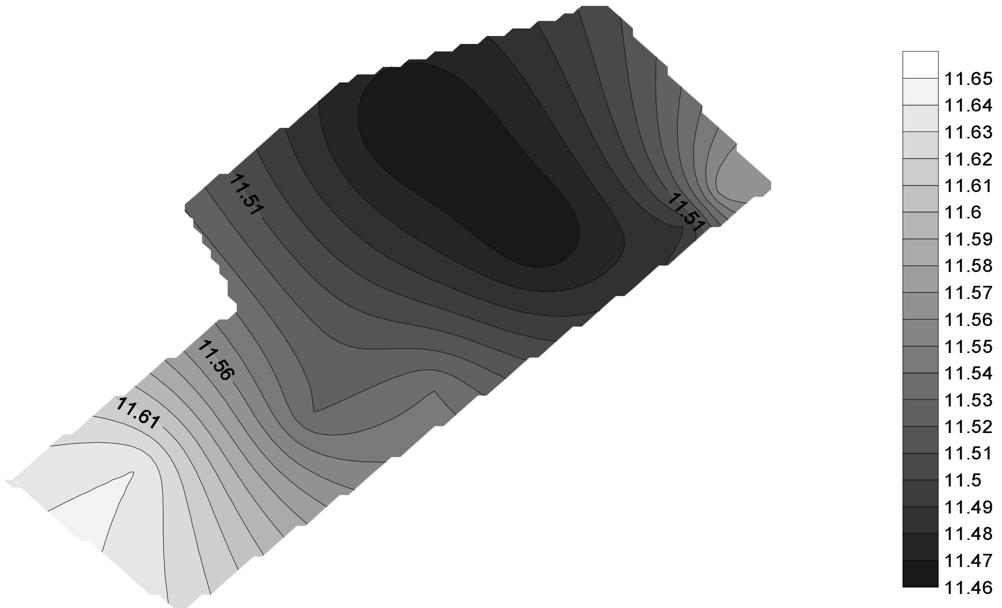

Figure 6.8: October 2004 average 1.5m air temperature

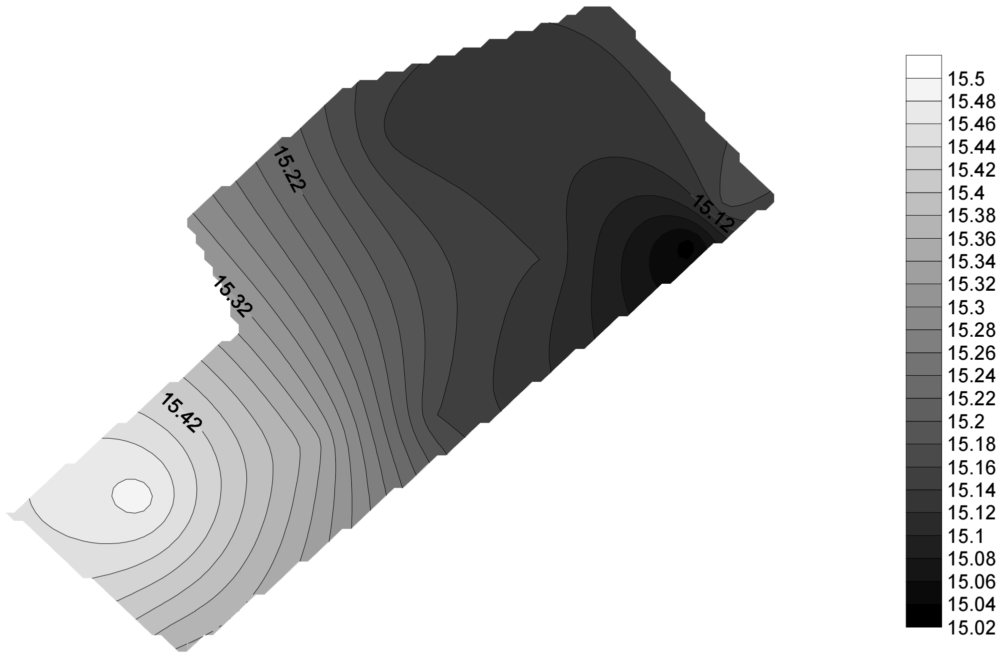

Figure 6.9: November 2004 average 1.5m air temperature

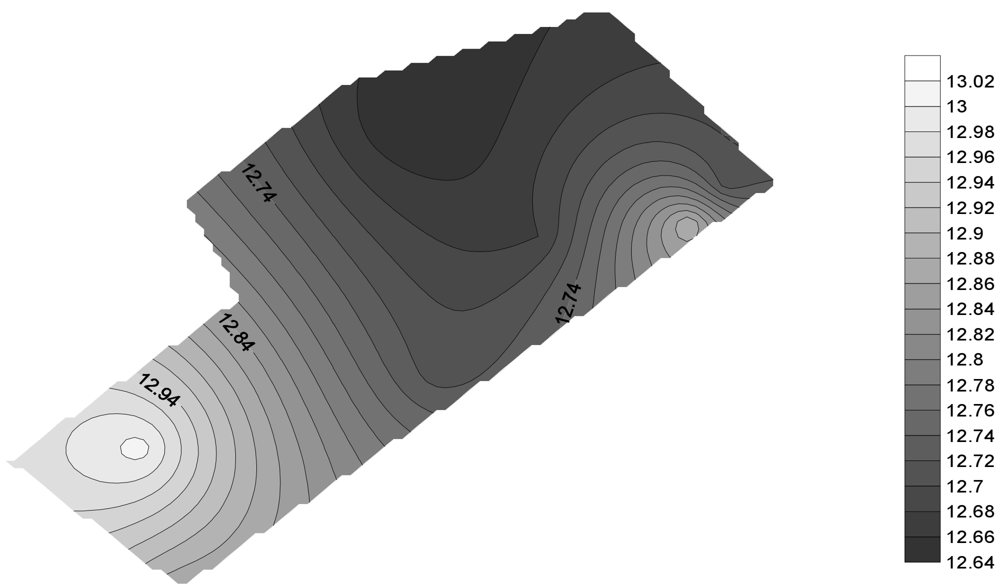

Figure 6.10: December 2004 average 1.5m air temperature

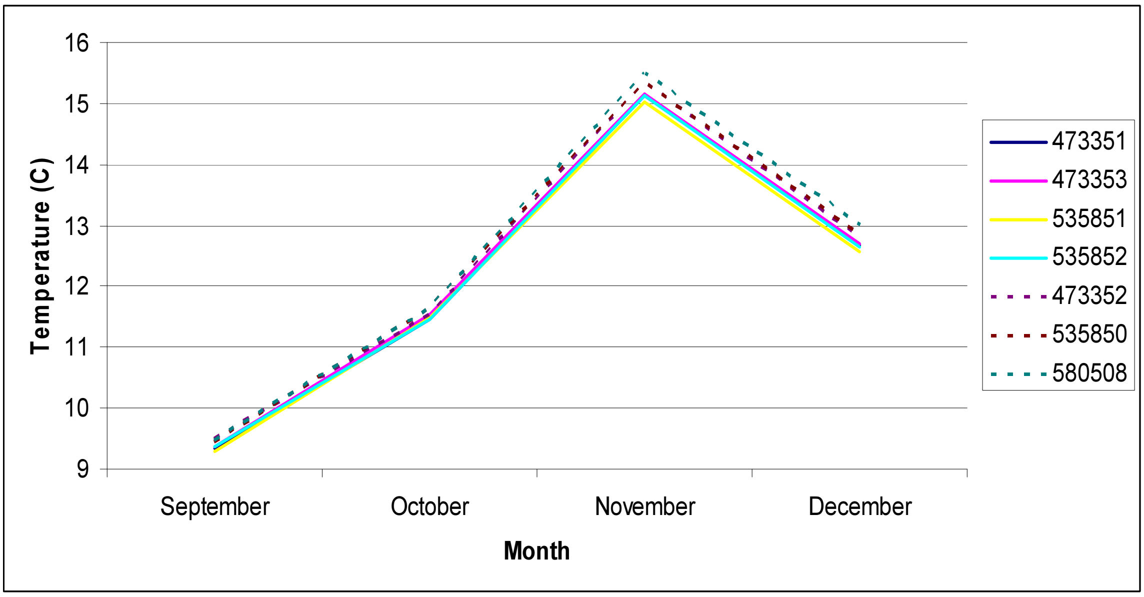

Figure 6.11: Monthly averages of 1.5m air temperatures. Dashed lines represent the HOBOs situated on the lower terrace.

6.3.2 1m air temperature (fruitline/canopy level)

The average 1m air temperatures over the study period only varied by 0.5°C overall between the different sensors. The maximum temperatures recorded varied by 1.98 C and the minimum temperatures by 0.91C overall. Table 6.4 illustrates the average, maximum and minimum temperatures taken from each HOBO as well as the monthly averages for each of the HOBOs.

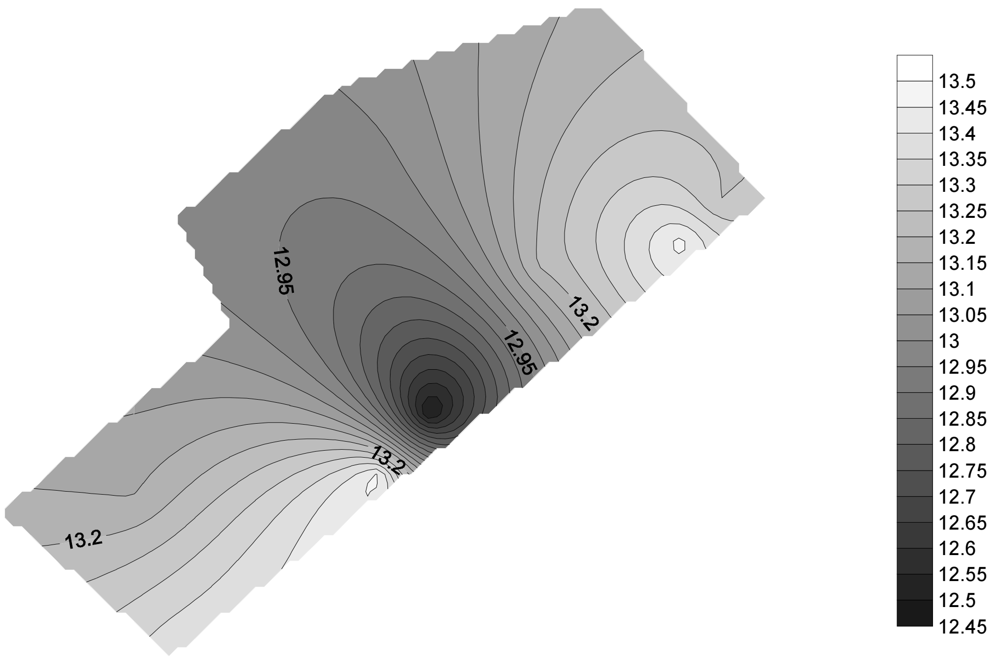

Figure 6.11: Average 1m air temperatures

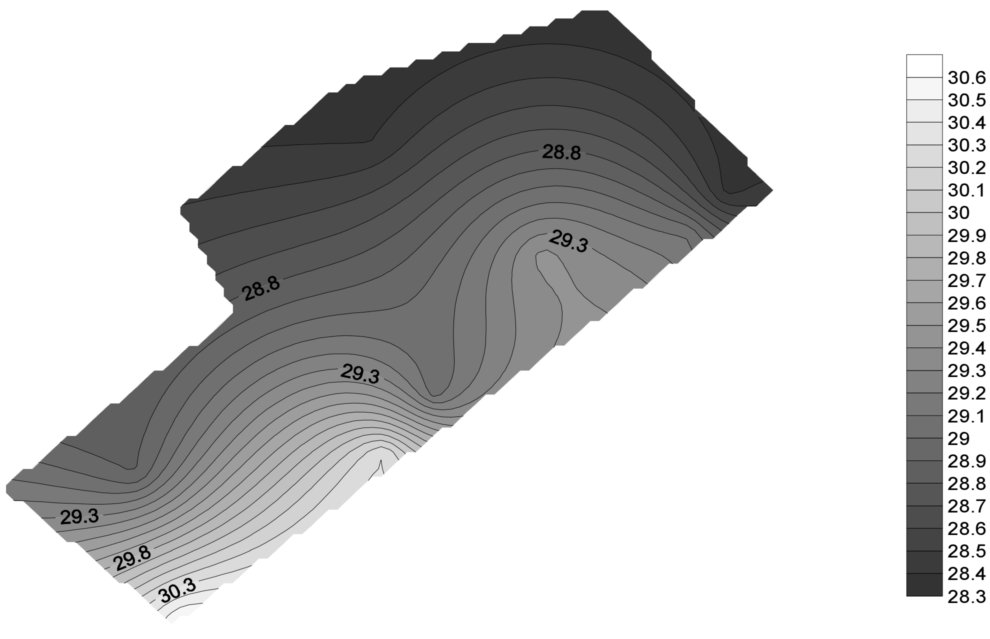

Figure 6.12: Maximum 1m air temperatures

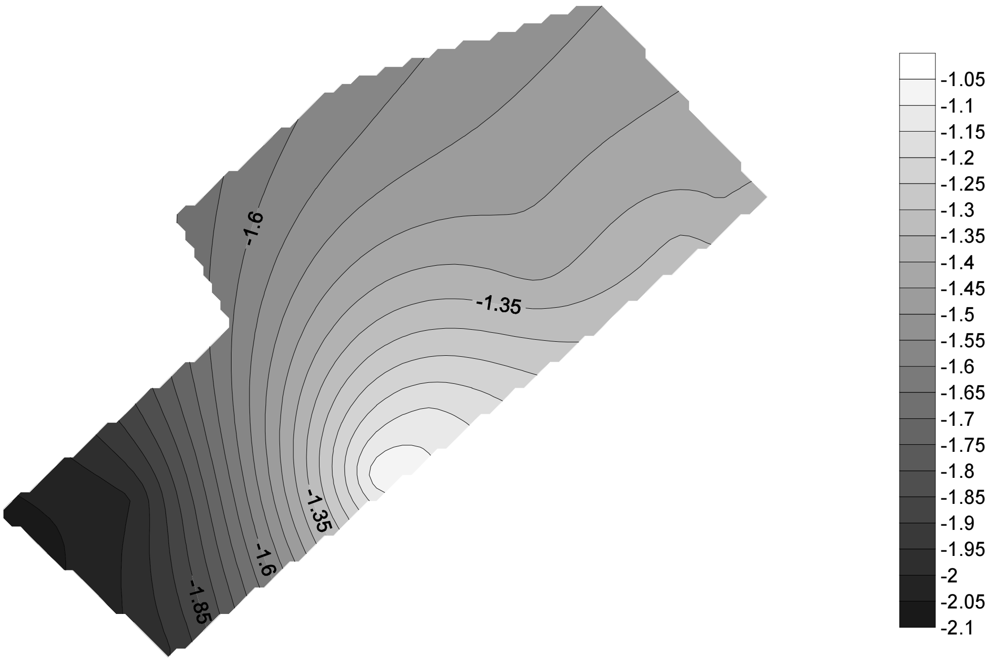

Figure 6.13: Minimum 1m air temperatures

Figure 6.11 shows that there is an increase temperature from the northwest corner of the vineyard towards the eastern edge of the lower terrace. The maximum temperatures measured tend to follow the same pattern as the average temperature with the highest of the maximum temperatures being the eastern edge of the lower terrace and the coolest temperatures being found at the northwest corner of the upper terrace (Figure 6.12). The minimum temperatures were found in the western corner of the lower terrace (Figure 6.13).

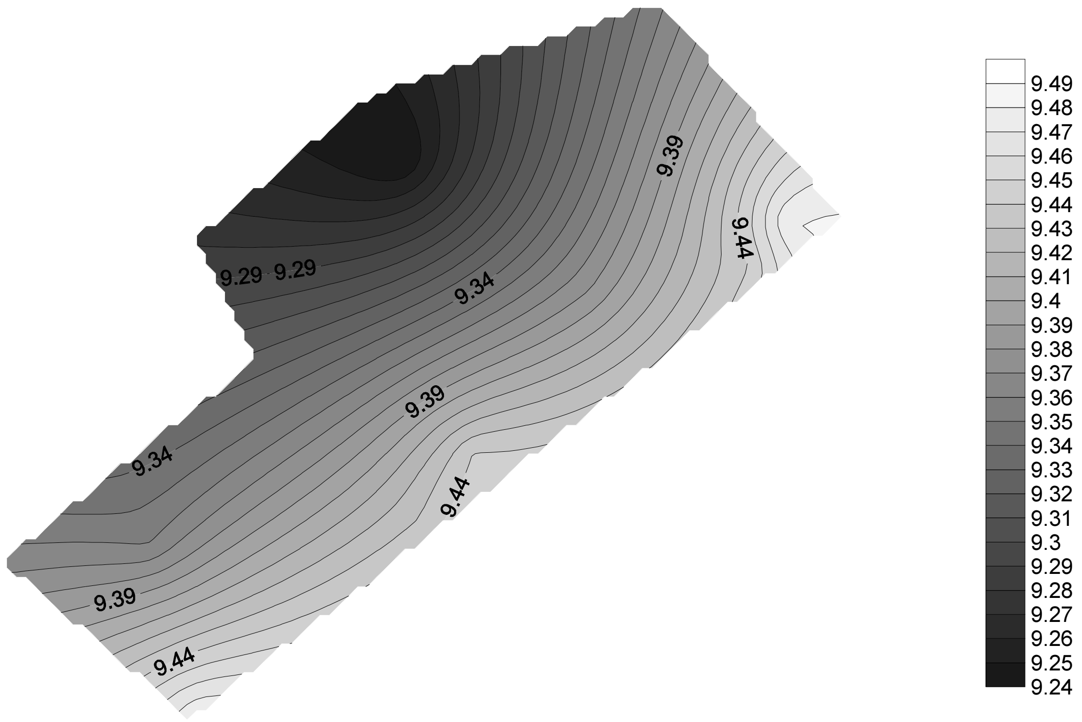

Figure 6.14: September 2004 average 1m air temperature

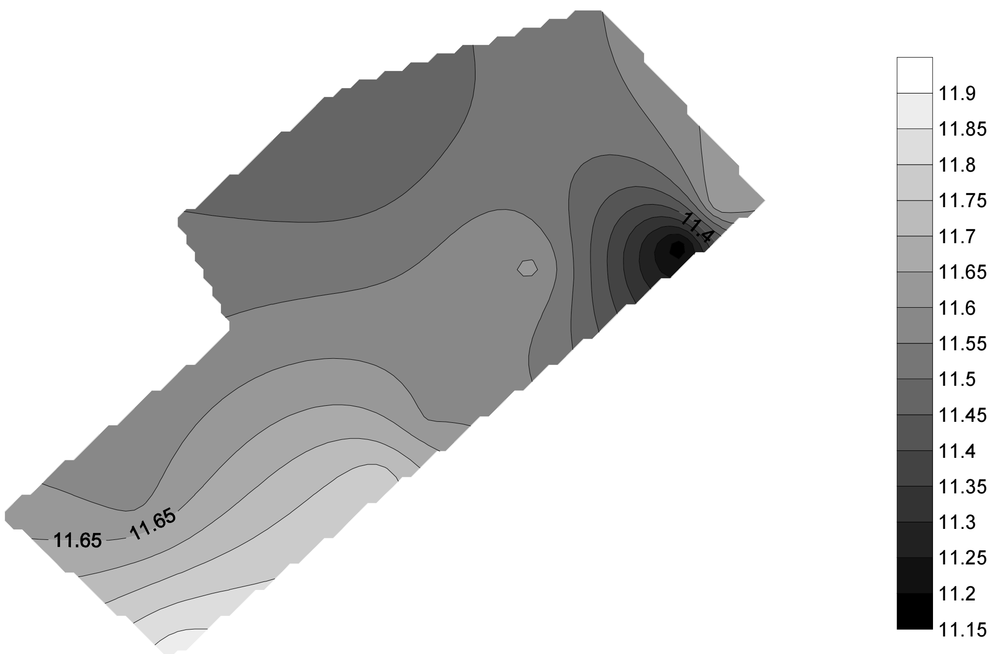

Figure 6.15: October 2004 average 1m air temperature

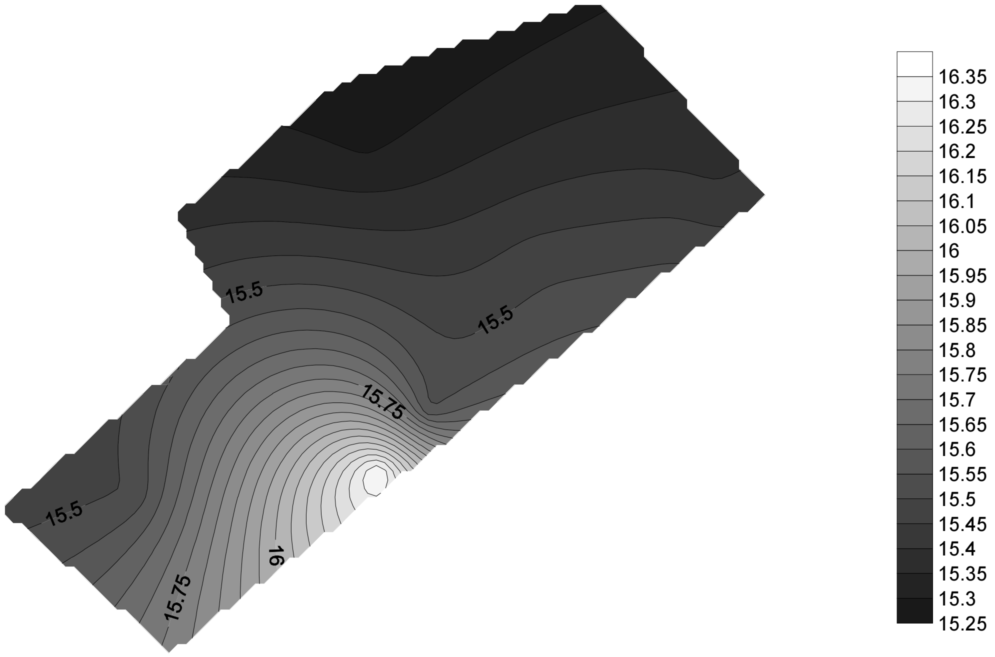

Figure 6.16: November 2004 average 1m air temperature

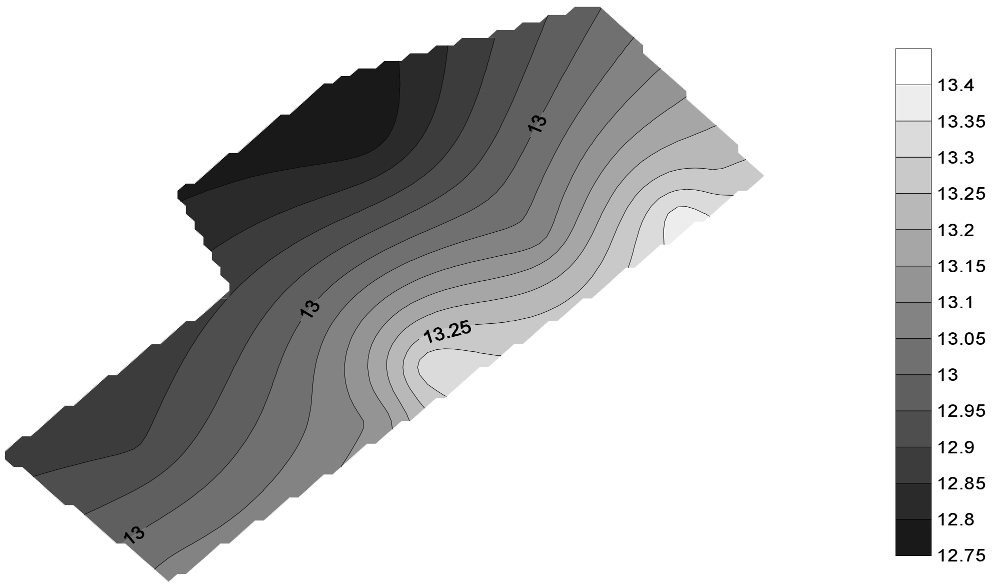

Figure 6.17: December 2004 average 1m air temperature

The monthly temperature averages tend to follow the same pattern as the overall study period. The monthly averages can be seen in Table 6.4. Figures 6.14 – 6.17 show that the higher temperatures are again found in the eastern side of the lower terrace. Figure 6.18 clearly shows that the HOBOs on the lower terrace recorded warmer monthly averages.

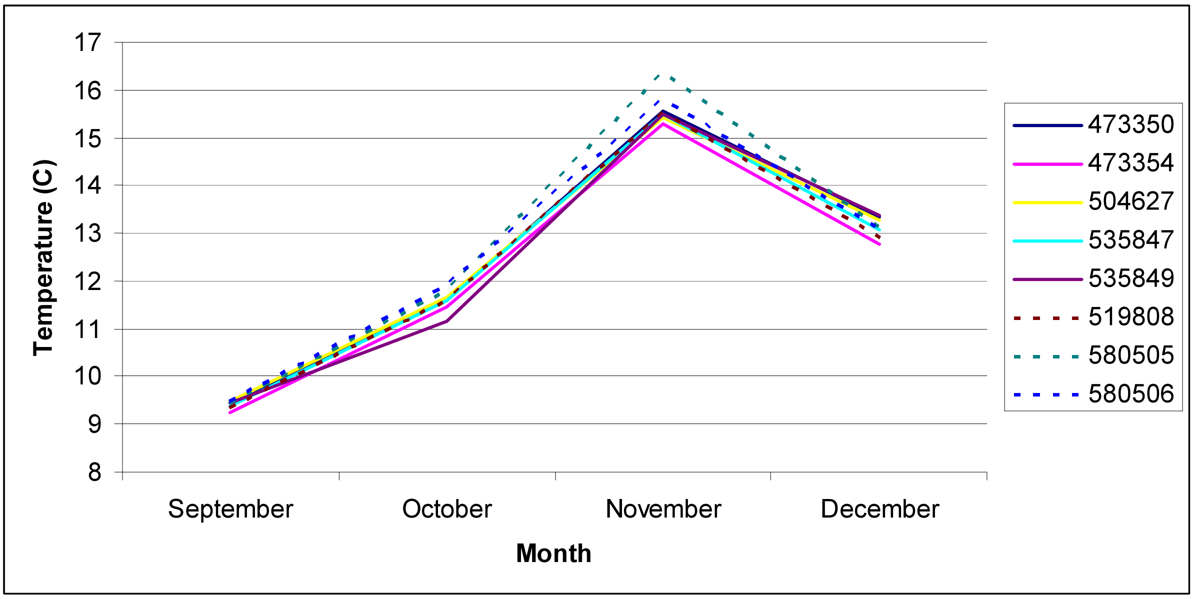

Figure 6.19: Monthly averages of 1m air temperatures. Dashed lines represent the HOBOs situated on the lower terrace.

Table 6.4: Maximum and minimum temperatures, overall and monthly temperature average, 1m air temperature for each HOBO.

	Upper Terrace						Lower Terrace		
	473350	473354	504627	535847	535849	580507	519808	580505	580506
Average Temp(oC)	12.48	12.98	13.25	13.2	13.47	12.99	13.15	13.46	13.39
Max temp	29.05	28.4	28.38	29.43	29.08	28.38	28.9	30.3	30.63
Min temp	-1.14	-1.54	-1.4	-1.43	-1.34	-1.09	-2	-1.06	-1.94
September	9.44	9.24	9.48	9.38	9.44	9.43	9.36	9.43	9.48
October	11.59	11.45	11.65	11.61	11.16	11.57	11.58	11.78	11.89
November	15.55	15.29	15.41	15.48	15.48	15.17	15.51	16.36	15.78
December	13.34	12.76	13.26	13.07	13.38	12.71	12.89	13.11	13.08

6.3.3 Soil temperature

The average soil temperatures over the study period only varied by 1.37°C overall between the different sensors. The maximum temperatures recorded varied by 2.82 C and the minimum temperatures by 14.5C overall. Table 6.5 illustrates the average, maximum and minimum temperatures taken from each HOBO as well as the monthly averages for each of the HOBOs.

Table 6.5: Maximum and minimum temperatures, overall and monthly temperature average, soil temperature for each HOBO.

	Upper Terrace					Lower Terrace		
	473350	473354	504627	535847	535849	519808	580505	580506
Average Temp(oC)	14.61	14.49	14.61	14.72	15.55	15.86	15.7	15.36
Max temp	19.73	18.97	10.09	18.92	19.33	24.59	21.21	19.64
Min temp	7.68	8.53	8.16	8.73	8.65	5.86	8.68	9.64
September	9.87	9.94	9.71	9.9	10.29	9.67	10.37	10.73
October	12.13	12.4	12.4	12.16	13.4	13.41	13.19	13.03
November	17.38	16.67	17.41	17.09	19.39	19.4	18.83	17.87
December	15.46	15.1	15.31	15.67	15.92	15.67	16.19	16.26

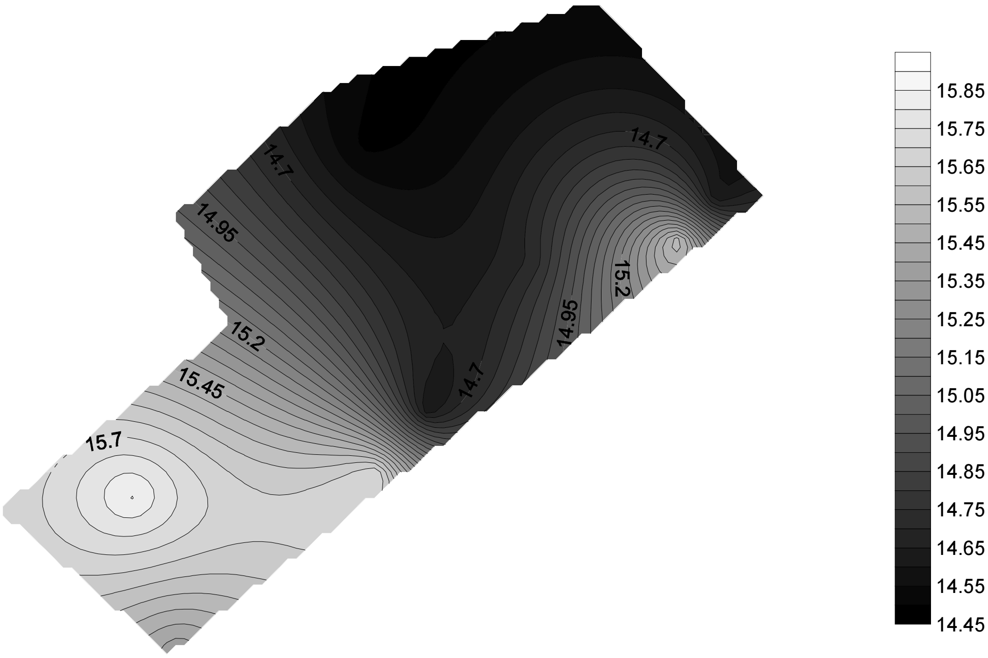

Figure 6.20: Average soil temperatures

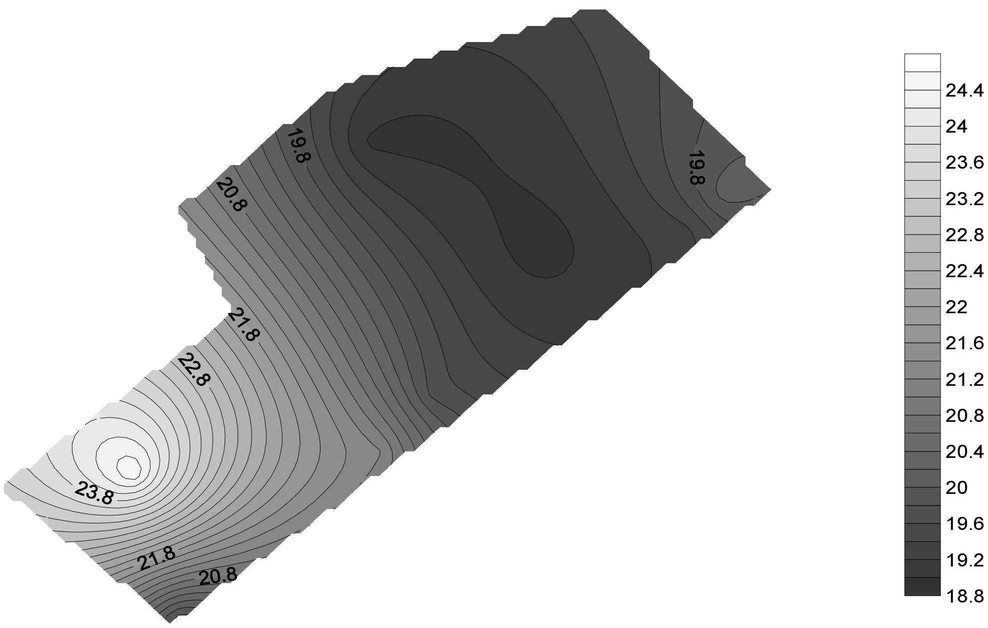

Figure 6.21: Maximum soil temperatures

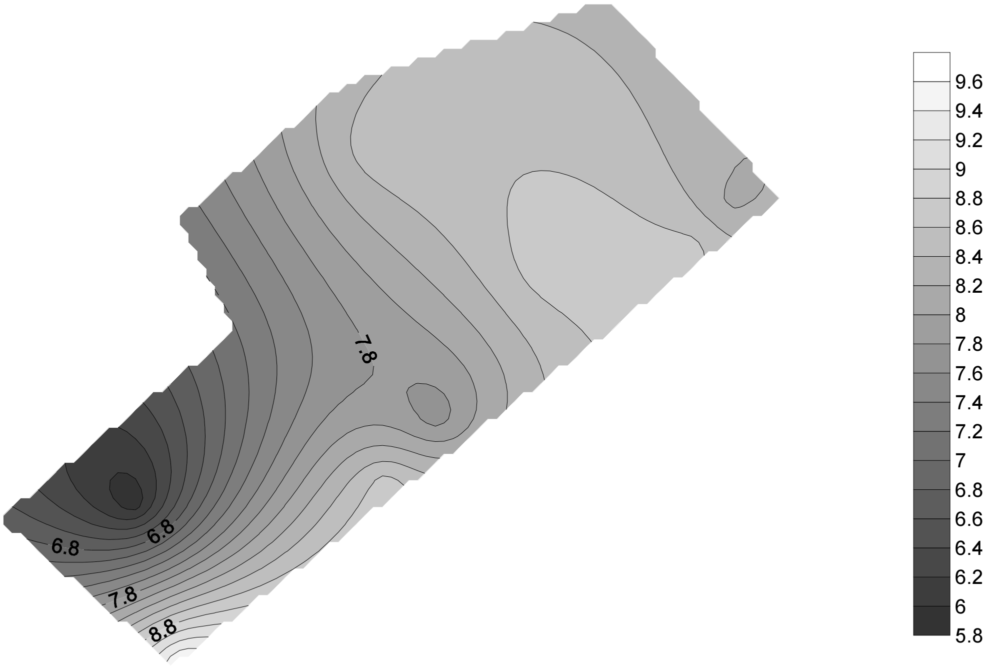

Figure 6.22: Min soil temperatures

Figure 6.20 shows that the warmest average temperatures were found in the bottom terrace towards the western corner with a warm patch near the eastern corner of the upper terrace. The highest temperatures recorded are found towards the western corner of the lower terrace (Figure 6.21). The minimum temperatures were also found in the western corner of the lower terrace (Figure 6.22).

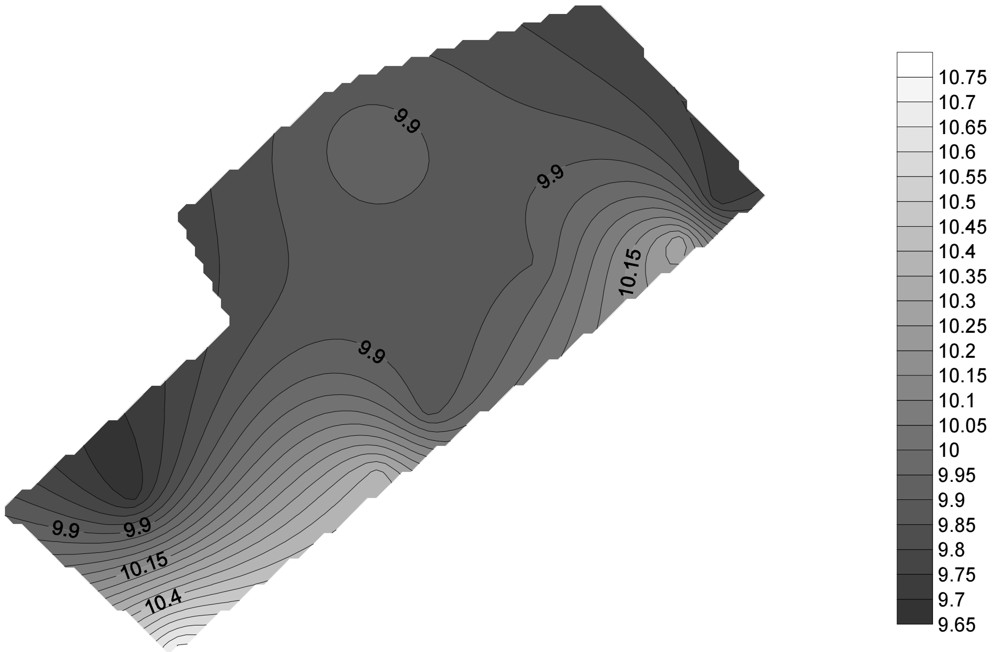

Figure 6.23: September 2004 average 1m soil temperature

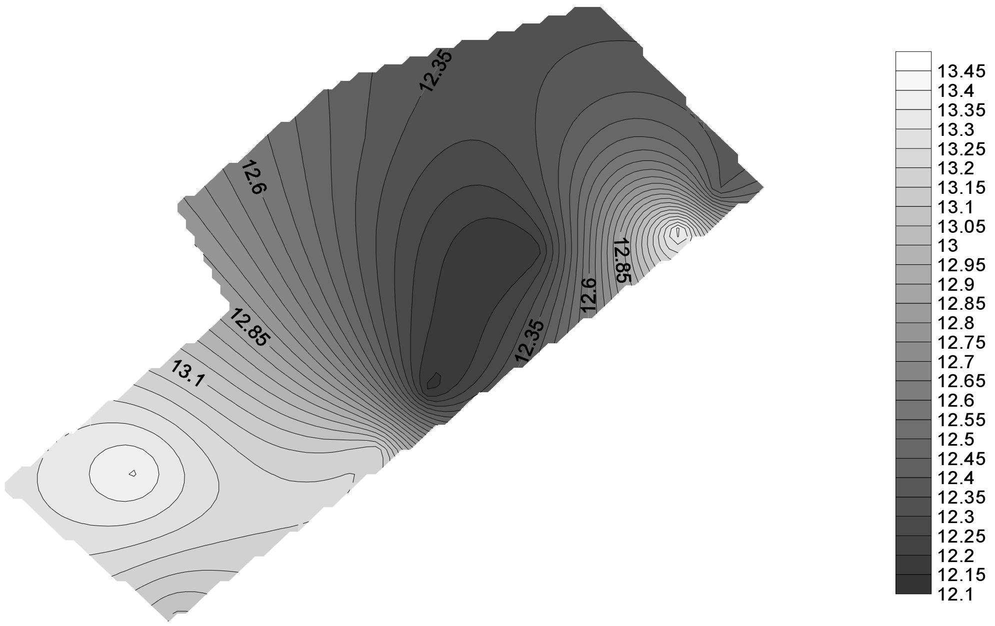

Figure 6.24: October 2004 average 1m soil temperature

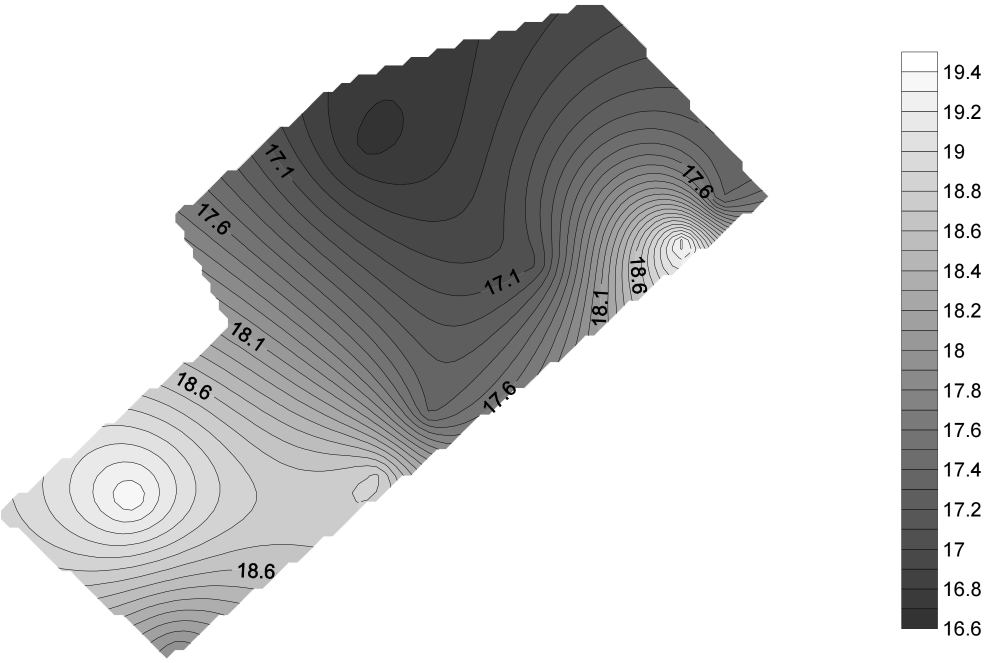

Figure 6.25: November 2004 average 1m soil temperature

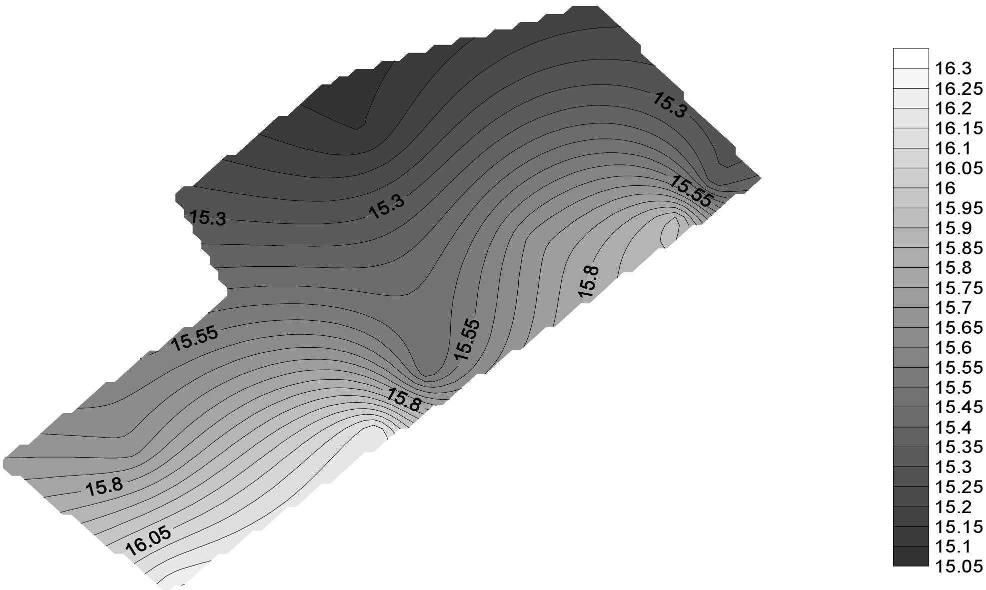

Figure 6.26: December 2004 average 1m soil temperature

The monthly temperature averages tend to follow the same pattern as the overall study period. The monthly averages can be seen in Table 6.5. Figures 6.23 – 6.26 show that the higher temperatures are again found in the western of the lower terrace, with the warm patch again showing near the eastern corner. Figure 6.27 clearly shows that the HOBOs on the lower terrace recorded warmer monthly averages with the exception of 5355849.

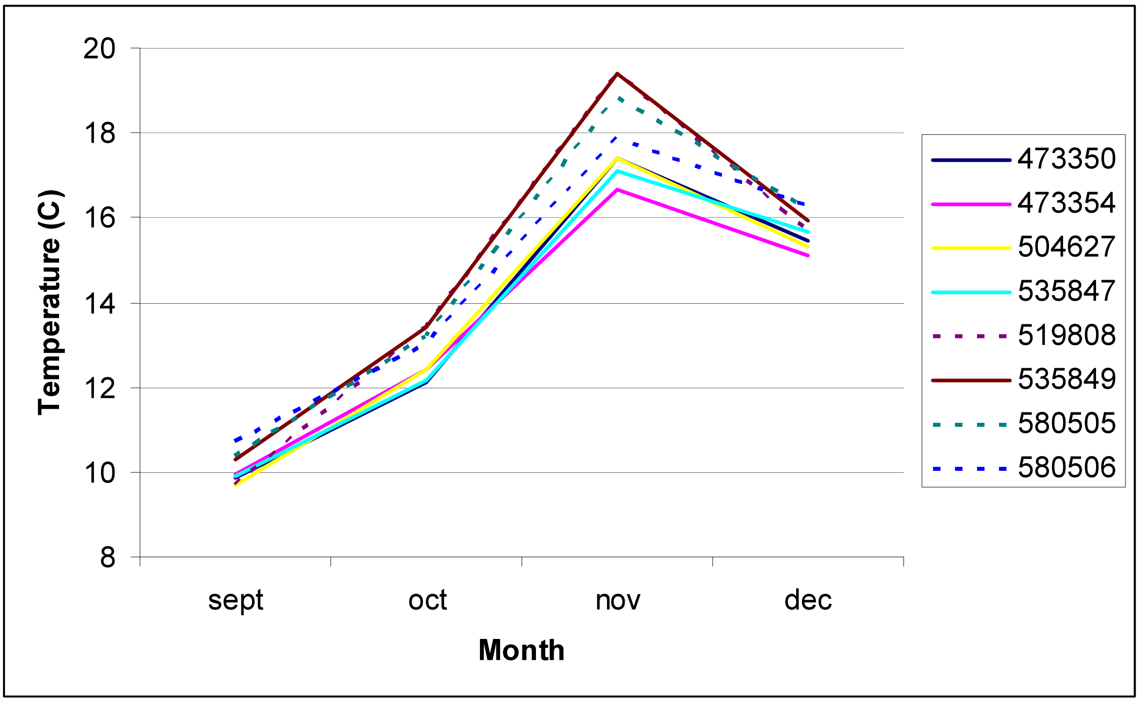

Figure 6.27: Monthly averages of soil temperatures. Dashed lines represent the HOBOs situated on the lower terrace.

6.3.4 Grapevine growth and development

Throughout the assemblage of the grape growth and development data it was found that parts of the data especially in reference to the growth data was somewhat unclear and some data appeared to be missing. However, data that was found to be useful was collated.

Figure 6.28 shows the growing season timeline and when the significant stages of grapevine development occur. The first stages of development (stage 02) occurred in the Riesling located in the upper terrace at the very end of September. By the 11th of October the grapevines had experienced stage 05 with the exception of the Sauvignon Blanc on the lower terrace, which had experienced it by the 18th of October. All the grapevines had reached stage 12 by the 1st of November. For the month of November the grapevines all experienced the same stages at the same time. On the 3rd of December the grapevines on the lower terrace were both at stage 15 with the Sauvignon Blanc on the upper terrace being at stage 17 and the Riesling on the upper terrace being at stage 21. By the 29th of December all the grapevines had reached stage 25 with the exception of the Sauvignon Blanc on the lower terrace.

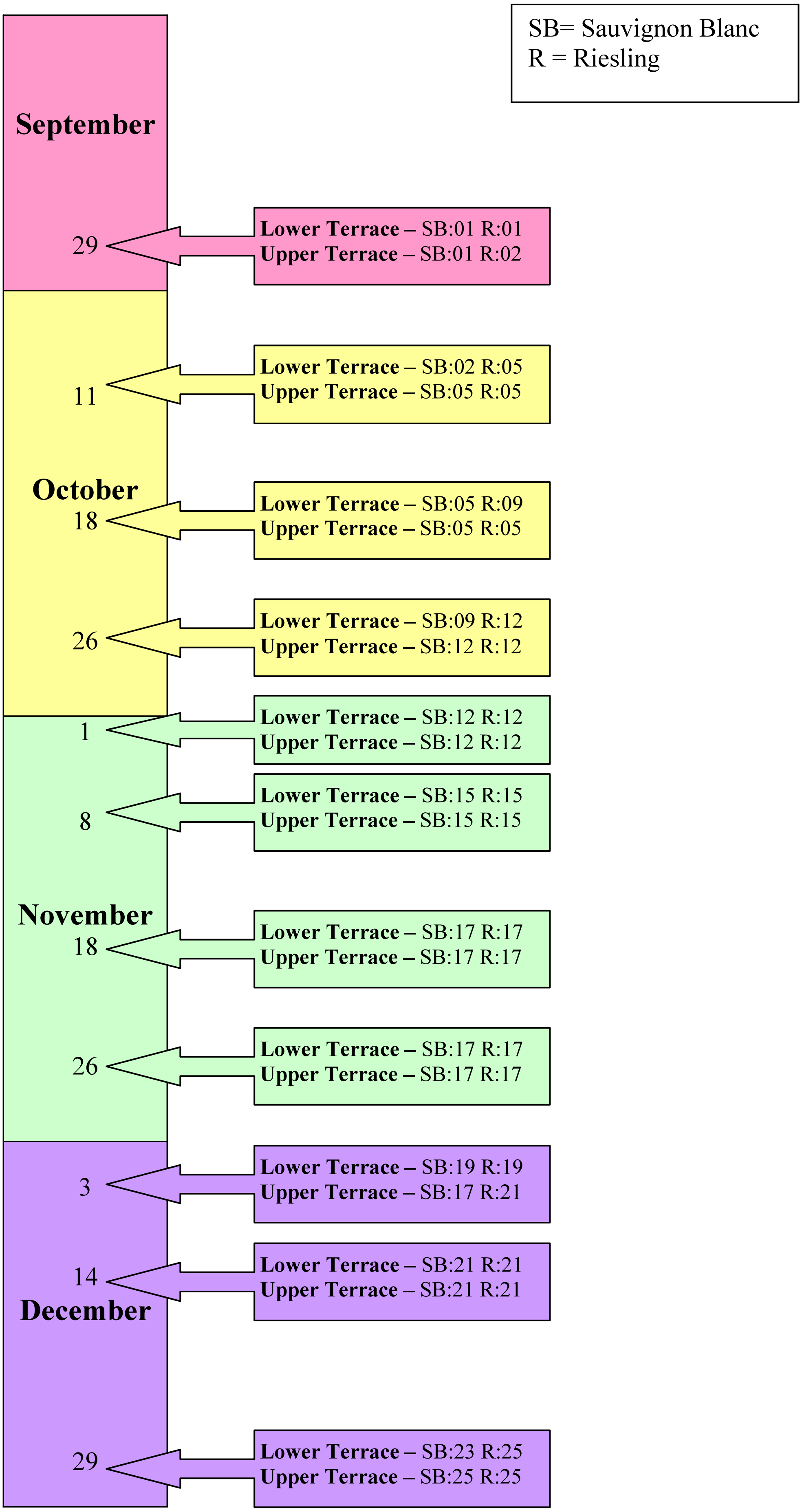
SB= Sauvignon Blanc
R = Riesling
September
29
Lower Terrace – SB:01 R:01
Upper Terrace – SB:01 R:02
11
Lower Terrace – SB:02 R:05
Upper Terrace – SB:05 R:05
October
18
Lower Terrace – SB:05 R:09
Upper Terrace – SB:05 R:05
26
Lower Terrace – SB:09 R:12
Upper Terrace – SB:12 R:12
1
Lower Terrace – SB:12 R:12
Upper Terrace – SB:12 R:12
8
Lower Terrace – SB:15 R:15
Upper Terrace – SB:15 R:15
November
18
Lower Terrace – SB:17 R:17
Upper Terrace – SB:17 R:17
26
Lower Terrace – SB:17 R:17
Upper Terrace – SB:17 R:17
3
Lower Terrace – SB:19 R:19
Upper Terrace – SB:17 R:21
14
Lower Terrace – SB:21 R:21
Upper Terrace – SB:21 R:21
December
29
Lower Terrace – SB:23 R:25
Upper Terrace – SB:25 R:25

Figure 6.28: Timeline of stages of grapevine development. The numbers represent the Stages of grapevine development shown in Figure 3.1.

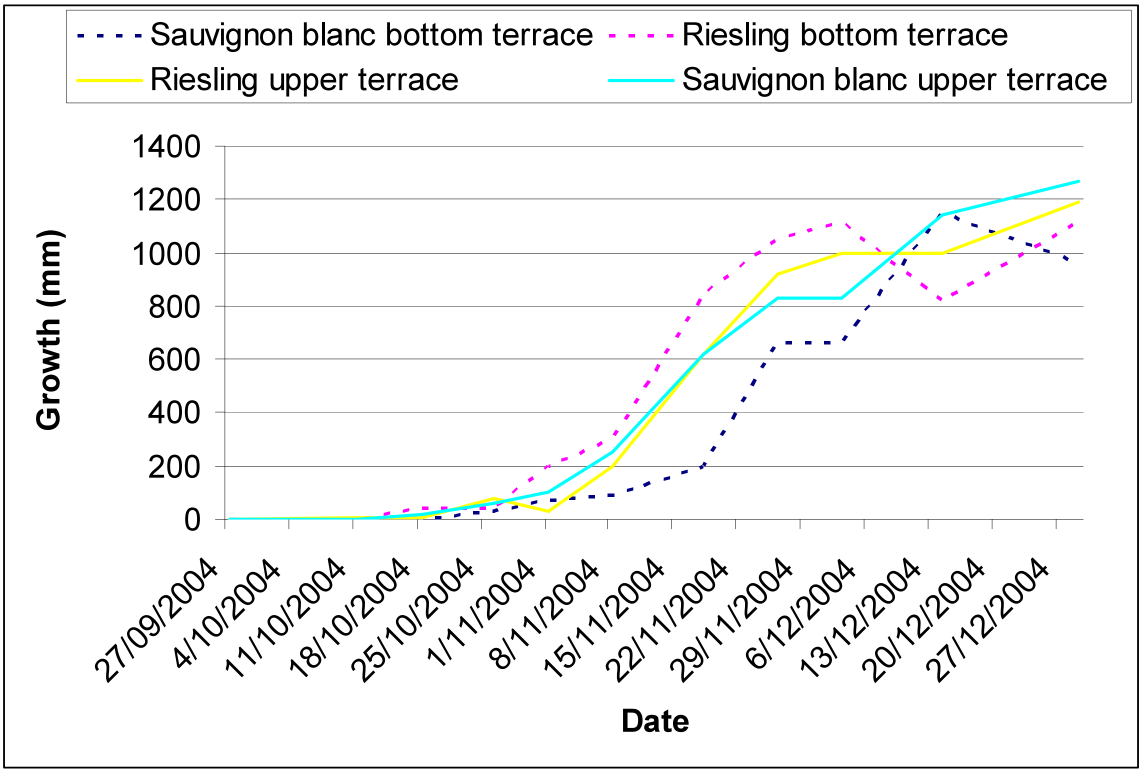

Figure 6.29: Growth of Sauvignon Blanc and Riesling grape varieties on the upper and lower terrace. Dashed lines represent the HOBOs situated on the lower terrace.

Figure 6.29 is a comparison of the grapevine growth of the Sauvignon Blanc and Riesling grape varieties on the upper and lower terrace over the growing season. Sauvignon Blanc growth rates appear to be very similar with the Sauvignon Blanc on the lower terrace growing at a slower arte than that growing on the upper terrace. The growth rate of the Riesling on the upper terrace is less than that on the lower terrace.

6.3.5 Meteorology

Figure 6.30 shows that towards the end of the growing season a significant of rainfall occurred, when in comparison with the rest of the growing season. There was a total of 211.6mm of rainfall for the growing season. Figure 6.31 shows the wind speed for the growing season. On Julian day 337 (2nd December) the strongest wind speed was recorded with 14.22 m/s. Figure 6.32 shows the wind direction for the growing season. It also shows that on Julian Day 337 the strong wind that was experienced was a Northwesterly.

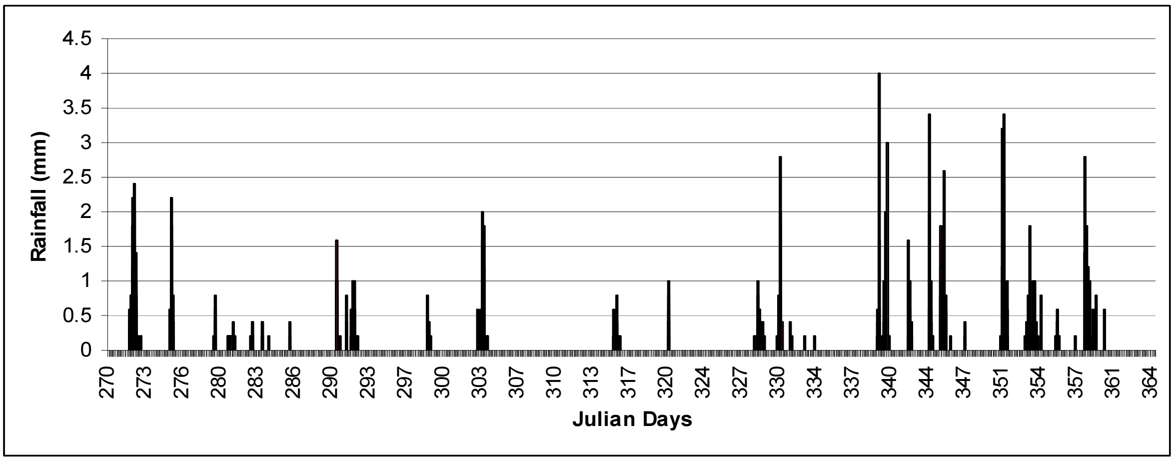

Figure 6.30: Rainfall for the growing season

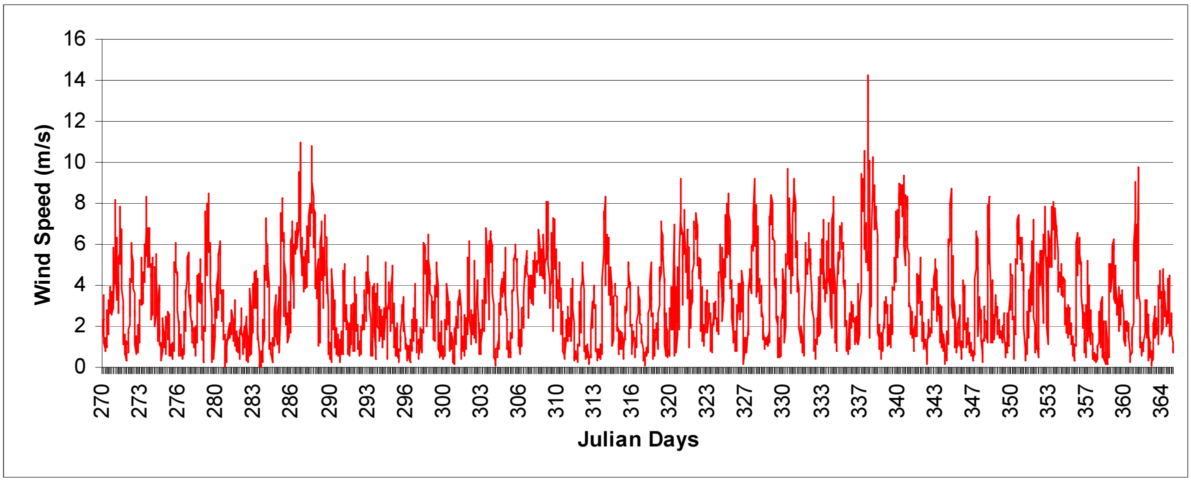

Figure 6.31: Wind speeds for the growing season

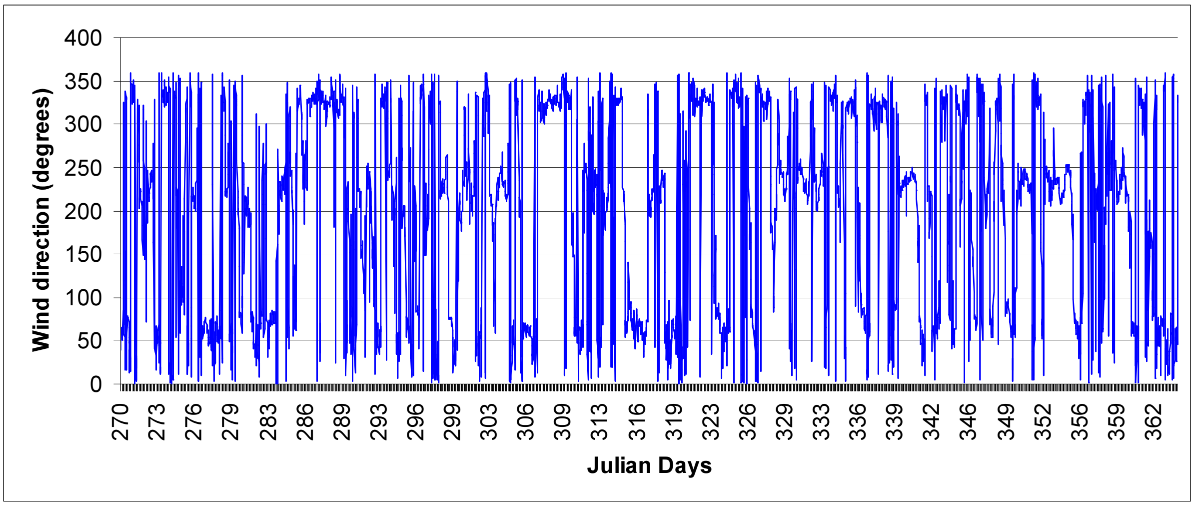

Figure 6.32: Wind direction for the growing season

Table 6.6 shows that for the AWS the average temperature was 12.96°C. The maximum temperature was 27.4°C and the minimum temperature was -0.43°C. The wind speed average was 3.13m/s and the average wind direction was 199° (Southwest). The relative humidity was on average 34% and the soil temperature averaged at 14.54°C.

Table 6.6 Average, maximum and minimum values from the AWS

	Average	Maximum	Minimum
1 .5m air temperature (°C)	12.96	27.84	-0.43
Rainfall (mm)	0.05	4.00	0.00
Wind speed (m/s)	3.13	14.22	0.00
Wind direction (degrees)	199	-	-
Relative humidity (%)	34	72	11
20cm soil temperature (°C)	14.54	20.31	7.42

6.3.6 Frost case study

The coldest frost event of the study period occurred on the night of the 2nd - 3rd June 2003. The temperature reached a maximum of 12°C for the day at 15:47. The temperature started to drop and reached 0°C at 03:41. Then temperature then began to rise and fall but eventually plunged to the coldest temperature of –1.51°C at 07:01 in the morning at the HOBO 473351. The HOBO 580508 was the first to drop to zero at 03:41. The rest of the HOBOs followed suit. By 07:45 all of the HOBOs were above zero. It was noted that the HOBO 4733582 never dropped in temperature as much as the other HOBOs (Figure 6.31).

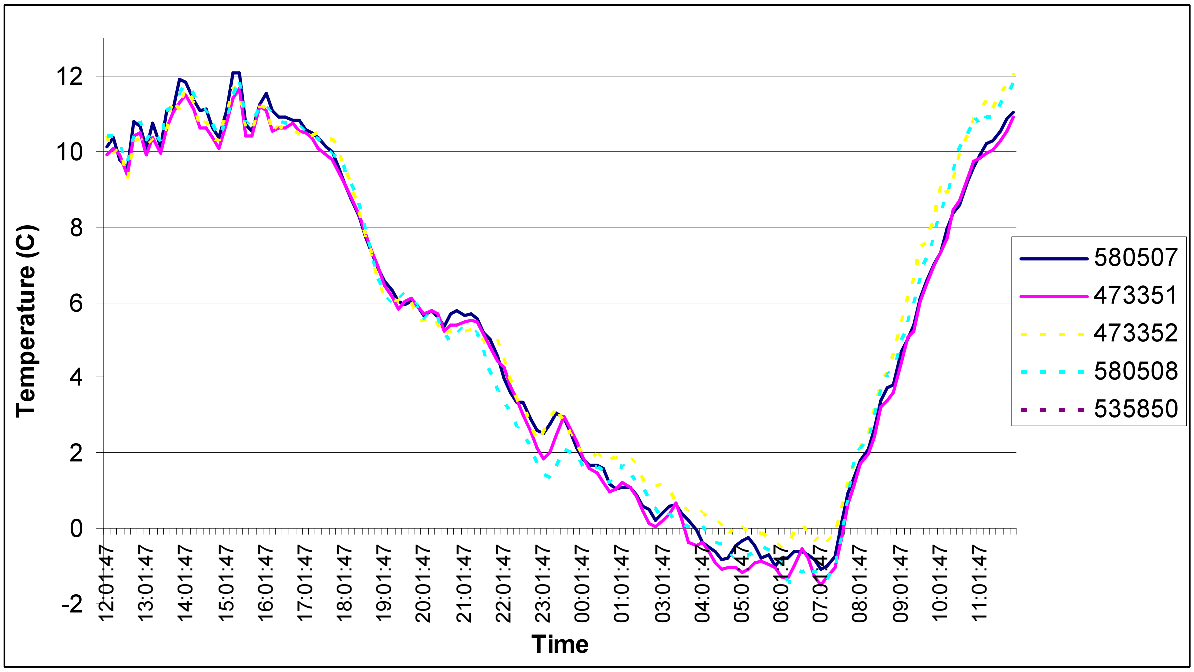

Figure 6.33: Hobo temperature data for the 2nd (12:00) – 3rd (12:00) October 2004. The dashed lines represent HOBOs on the lower terrace.

6.3 Summary

The results and data analysis were presented for both the Waipara basin and the McKenzie Vineyard. For the Waipara Basin the temperature data collected from the four vineyards was graphed into monthly summaries. From this data climate indices were calculated. For the McKenzie vineyard temperature contour maps were created for the 1.5m and1 m air temperature and soil temperature. The stages of grapevine development and the grapevine growth were examined. Also the overall meteorology for the growing season was looked at. A case study of the coldest frost of the growing season was presented.

Chapter 7

Discussion

7.1 Introduction

The purpose of this chapter is to explain what and how specific climatic factors affect grapevine development and growth. This chapter describes first, the spatial variability of temperature across the Waipara basin. The climate indices; degree days, LTI and MTWM are then discussed. This is then followed by a discussion of the spatial patterns of temperatures within the McKenzie vineyard and how this affects the different grape varieties. Lastly the significant metrological events that occurred within the growing season are explored.

7.2 Waipara Basin July 2003 – November 2004

7.2.1 Spatial variability of temperature across the Waipara Basin

It was found that overall the Waipara West vineyard had the warmest monthly temperatures. It also recorded the highest temperature overall and was not affected by the cold as much as the other vineyards, whereas the other vineyards tend to more similar in their recorded monthly average temperatures. The River Terraces vineyard had a tendency to record more minimum temperatures than the other vineyards with Canterbury house recording the coldest temperature overall. The McKenzie vineyard had the warmer of the minimum temperatures overall. This all directly relates to the study that was conducted by Weldon (2003). His research on the viticulture potential of the Waipara Valley shows that the warmest temperatures occur within the flatter areas of the valley floor, where the vineyards are located. This means that these vineyards are located in the most favourable temperature conditions within the Waipara Basin. However, this location is also perfect for frost development due to its enclosed and low topography (Weldon 2003).

7.2.1 Climate indices

The degree days for each month in the study period were calculated for each vineyard. The months of June and July were not included due to the monthly temperatures being below the base temperature of 10 C. However it has been shown that even thought the average for the month is less then the base temperature of 10 C there may be some days when growth has occurred. Usually the degree days are collected for just seven months – October to April (and April to October for the Northern hemisphere) and then collated to show the overall total (Jackson 2001). For the purpose of this study, all the months above the base temperature have been collated. Canterbury House has the highest number of degree days at 1294, with the McKenzie vineyard coming second at 1192, followed by the River terraces vineyard. Waipara West has the least amount with 1064, but this is due to the no data for the months of September, October and November. So for the purpose of this comparison it will not be included. For the total number of degree days all the vineyards would be classified as Region I in Amerine and Winkler (1974) degree day classification. This means that the all the vineyards involved are considered to have cool climates. Jackson (2001) has stated that the majority of the high quality wines are produced in Regions I and II.

The Mean Temperature for the Warmest Month (MTWM) was calculated for the 2003 - 2004 growing season using January as the warmest month. January was used because even though all the months are not presented, it has been assumed for the purpose of this study that January is on average the warmest month (Coombe and Dry 1988).

7.3 McKenzie Vineyard; Growing season 27th September – 29th December 2004

7.3.1 Spatial patterns of warm and cold temperatures within the vineyard

It can be seen clearly from the results that there is spatial variations of temperatures within the vineyard occurring at all the levels (1.5m, 1m and soil) recorded. The monthly averages and the overall average for the period 27th September to 29th December 2004 showed that the upper terrace recorded cooler temperatures than that of the lower terrace.

It was found, that at all of the levels recorded, there was a trend towards the higher temperatures on the lower terrace. Also the lower terrace showed the lowest temperatures recorded. This spatial pattern of temperature can be explained firstly by the composition of the soils. The composition of the soil at each Hobo locations was noted (Appendix A). It was found that lower terraces soil was considerably gravelly and there were a lot of small rocks present on the soil. It has been stated that "the air temperature near the ground is influenced by the nature of the soil" (Geiger et al 2003). This is true in this case. During the day solar radiation is absorbed by the gravelly and rocky surface of the soil. This is then radiated into the surrounding air and soil beneath, increasing the temperatures. However, the 1m temperature contour maps did not show this relationship as strong as the contour maps of the 1.5m and soil temperatures. This is because these Hobos were located along the fruitline and within the canopy of the grapevine. There is a specific distinction between the microclimate of the rows of grapevines and the space between the rows. This is because during the day less sunlight infiltrates within the grapevine canopy whereas, in between the rows, the sunlight directly affects the ground surface. This therefore means that the temperatures within the canopy are lower than the temperature found within the rows (Geiger et al 1977).

The spatial pattern of temperature can also be explained by the topography of the vineyard. The coldest temperatures recorded during the frost case study were found at the southern end of the lower terrace. This particular area has the lowest elevation of the vineyard (Figure 5.3 and 5.4). Because this area has the lowest elevation, cool air flows down from the upper terrace due to gravity and forms a pool of cold air which therefore forms pockets of frost (Figure 7.1). Figure 7.1 Shows that due to the southern edge's proximity to Weka Creek, it is also affected by the cold air draining down the creek. The presence of a shelter belt on the eastern boundary may contribute to the pooling of the cold air by stopping the onward flow of the cold air down Weka Creek.

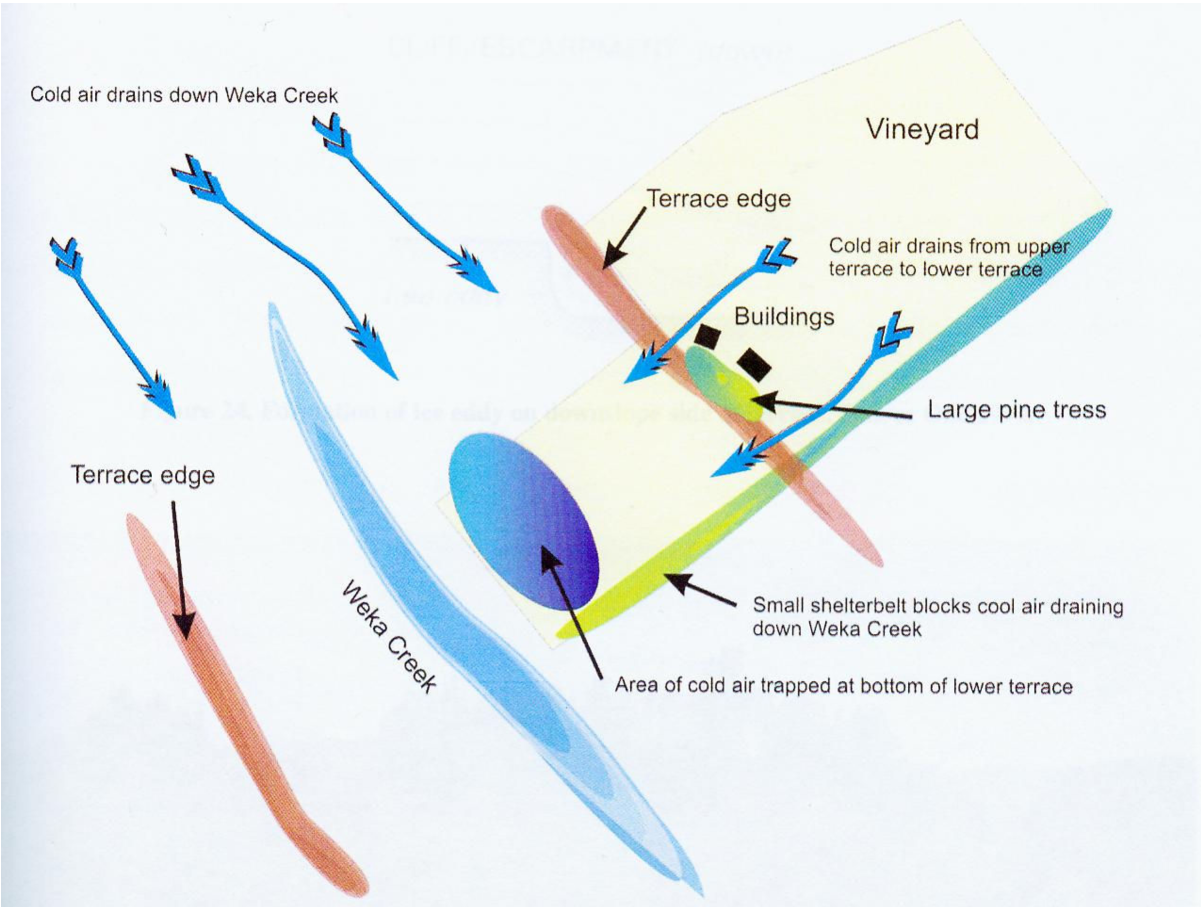

Figure 7.1: Drainage of cold air from higher elevations forming frost pocket at the southern end of the lower terrace (source; Ben Meuli 2005).

7.3.2 The influence of the temperature spatial patterns on the Sauvignon Blanc and Riesling grapevine varieties development and growth

Both grapevine varieties did not start to show signs of growth until the start of October. This is because the temperature was below the minimum temperature for growth (Jackson and Spurling, 1988; Fitzharris and Endlicher, 1996). Once this minimum temperature was reached in October growth began to occur. The first stages of development as defined by Coombe (1987) (refer to figure 3.1 and associated text) was seen in the Riesling located in the upper terrace at the very end of September. The Riesling tended to be the first to develop, especially the Riesling located on the lower terrace. The Sauvignon Blanc tended to be slower to develop, especially the Sauvignon Blanc located on the lower terrace. By the end of the study period all the grapevines had reached the late flowering stage with 80% of caps fallen, with the Sauvignon blanc on the lower having only reached the stage below which is full flowering with 50% of caps fallen. All of the stages occurred at the during the months they were supposed according to Galet (2000) growth cycle of the grapevine (Figure 3.3)

The spatial patterns of warm and cold temperatures (that are discussed in detail above in 7.3.1) have affected the growth of the two grapevine varieties studied. Firstly, the grapevines that are located on the upper terrace follow along the same growth trends. At the end of the growing season they both have accumulated more growth than the accumulated growth of the grapevines on the lower terrace. This shows that the upper terrace had more favourable temperatures overall for growth. This is due to the upper terrace overall temperature not varying as much in temperature as much as the lower terrace. The lower terrace had a tendency to experience both the highest and lowest temperatures. Any extremes in temperature can cause significant damage to the grapevine (Jackson 2001). The growth rates of the grapevines on the lower terrace varied greatly. The development observations of the Sauvignon occurred near the HOBO 535850 which is situated towards the south eastern corner of the lower terrace. The low temperatures that frequently occur towards the southern end of the lower terrace could be a limiting growth factor.

7.3.3. The effect of key metrological events on the Sauvignon Blanc and Riesling grapevine varieties development and growth

The most severe frost of the growing season occurred on the night of the 2-3 of October. This frost was noted in the development notes. It was also noted that due to this frost the Riesling on the upper terrace growth was affected. This can be seen in the upper terraces Riesling growth. When comparing the both Rieslings growth rates it can be seen that the upper terrace Riesling had a slow growth rate whereas the lower terrace Riesling had a reasonably rapid growth rate. The reason for this difference in growth rates is due to the frost that occurred. Frosts that occur around the start of the growing season are a significant problem for vineyard managers. Frosts at this time coincide with bud burst. At bud burst the grapevine is very susceptible to damage from any temperatures below -1C (Jackson 1997).

A considerably cold and wet period occurred during December of the growing season. This is clearly shown the average temperatures for the month of December at all three levels. The temperatures are significantly lower than that of the November temperatures. A noteworthy amount rainfall occurred during this time. This cold and wet period has affected the growth of all the grapevines. This is shown in clearly in figure 6.29. The growth rate for all of the grapevines shows a significant decrease in growth rate. The grapevines during this period of cold weather are at the flowering stage of development (Stages 19-25). The factors that influence this stage of development the most are the weather and the mean daily temperature. It has been shown that very few flowers will open at temperatures below 15.6^{o}C (Winkler, 1974).

On the 2nd of December a very strong northwest wind was recorded. The wind speed reached a maximum of 14.3m/s. Strong winds can have a very significant effect on grapevine development. They can cause a delay in the development depending on what stage the winds occur. For example if they occur around the time of flowering there can be delay in the following onset of fruit set (Smart,1987). Strong winds can also cause broken shoots to occur (Pearson and Goheen, 1988). This strong wind may have had affect on the growth rate of the grapevines. Nevertheless, as it was not recognised in the development notes and it also occurred during the cold period, it can not be conclusively stated whether it was a factor in the decrease in the growth rate of the grapevines or whether it caused any damage to grapevines which would consequently affect the grapevines development.

7.5 Summary

There is variability of the monthly temperatures within the Waipara Basin. However, these temperatures show that the basin has very favourable temperature conditions perfect for viticulture. The climate indices, Degree Days and Mean Temperature of the Warmest Month support this theory. Within the vineyard there were distinctive spatial temperatures patterns. These spatial patterns had an effect on the grapevines development of both the Riesling and the Sauvignon Blanc. As well as the significant meteorological events those were found to have occurred. It was found that temperature influences the growth and development of the grapevine more than any other climatic factor.

Chapter 8

Conclusions

8.1 Introduction

The purpose of this chapter is to summarise the main findings of the study. Firstly the overall aim and objectives of the study that was discussed in the first chapter with be re-visited, followed by a discussion of the main findings of the study and how they relate to the aims and objectives. Next the limitations of the study are discussed. The chapter then concludes with suggestions for future research.

8.2 Summary of main findings

The overall aim of this research is to improve understanding of the influence of the climatic environment on grapevine development at the meso- to micro-scale. This includes an understanding of:

1. How microclimatic factors influence the development of the grapevine over the growing season in a single vineyard (McKenzie Vineyard) on McKenzies Road in Waipara.
2. The local to regional scale climate processes that make the Waipara Basin such a good area for viticulture.

These general objectives can be broken down into more specific aims of this study, as follows:

- To compare the physiological response of grapevines of different varieties to micro-climate variations within the McKenzie vineyard.
- To identify the small-scale spatial pattern of warm and cold areas within the vineyard, and their significance for the physiological development of differing grape varieties.
- To examine the effect of key meteorological events (such as frost, windy or cold periods) on grapevine physiological development during the growing season.
- To investigate the variability in climate across the Waipara Basin wine producing area, using meteorological data from a number of different vineyards.

It was found that the most important climatic factor that influences grapevine development and growth was temperature. Temperature influenced certain stages of the grapevine development. For example that bud burst will only occur when the temperatures reach 10 ºC or above. Also the spatial pattern of temperature within the vineyard effects the growth and the development of the grapevine. This spatial pattern affects both the Riesling and Sauvignon Blanc grape varieties similarly, but it was found that the Riesling variety developed quicker overall. In addition the significant metrological events that were identified; the cold wet, period in December, the frost event and the severe wind event may have had an affect on the development of the grapevine but was not entirely conclusive. It was found that there was some variability in temperature across the Waipara Basin which was expected. The research has suggested that according to the climate indices the area is a good place for viticulture to occur.

8.3 Limitations

There are some limitations of the research. Firstly, the length of the study period for the growing season was not long enough. The ideal length of time would be to cover the entire length of the growing season. This was not done due to time restraints of the study. Also, the lack of long term data for the Waipara basin vineyards meant that the long term climate variability could not be examined. The grapevine development data was somewhat ambiguous and some parts were missing. However, there was useful information and this was used appropriately. This could be improved by the use of standardised grape development and growth forms which would eliminate any ambiguous and incomplete data.

8.4 Future research

Overall the research has been successful in providing an insight into how, what climatic factors affect grapevine growth and development. However due to the limitations discussed above there is scope for future research.

- The entire growth season should be examined. This includes continuing the use of the HOBO network within the vineyard but including far more detailed grapevine growth and development. To gain a better understanding of how temperature influences the development of grapevine over the growing season as a whole. As well as having a more in depth understating of the differences between the different grape varieties that are grown.
- Longer term climate data from the within the Waipara basin would be essential to get a complete picture of the variability of climate within this area.

- A number of growing seasons should be examined to see how the temperature affects the grapevine over time.

Chapter 9
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Appendix A

Table A1: HOBO serial numbers and details

HOBO number	Details
473350	Upper terrace Starts 19/05/04 Canopy level Soil temp Lower terrace pinot noir Row 106 (Top) Dry soil
473351	Upper terrace Starts 01/01/04 Air temp 1.5m only Chardonnay Row C67 (Top near shed)
473352	Lower terrace Starts 01/01/04 Air temp 1.5m only Sav Blanc Row SB26 (Bottom)
473353	Upper terrace Starts 01/01/04 Air temp 1.5 m only Lower terrace pinot noir Row 106 (Top) Dry Soil
473354	Upper terrace Starts 06/07/04 Canopy level and soil temp (1m + 50cm) Pinot gris Row PG18
504627	Upper terrace Starts 19/05/04 Fruitline and soil temp Riesling Row 11 Bad soil data from 07/01/05 Very dry soil
535847	Upper terrace Starts 06/07/04 Fruit line and soil temp Chardonnay Row C67 (Near shed) Very dry soil

519808	Lower Terrace Starts 19/05/04 Fruit line and soil temp Cabernet sauvignon Row CS44 Gravely dry soil
535851	Upper terrace Starts 07/06/04 Air and Sauvignon blanc Row SB25
535852	Upper terrace Starts 01/01/04 Air temp Pinot noir (Top) Row PN18
580505	Lower Terrace Starts 19/05/04 Soil and fruit line temperature Riesling Row R8 (Bottom) Gravely soil
580506	Lower Terrace Starts 19/05/04 Fruit and soil temp Sauvignon blanc Row SB3 (Bottom) Gravelly soil Damaged from 18/12/04 (soil) only affected
580507	Upper terrace Starts 19/05/04 1.5 Riesling Row 11 (Top)
580508	Upper terrace Starts 01/01/04 1.5m air temp Cabernet sauvignon Row CS44 (Bottom) Gravelly dry soil
535849	Upper terrace Starts 19/05/04 1m + soil temp Sauvignon blanc Row SB25
535850	Lower terrace Starts 01/01/04 1.5m air temp Sauvignon blanc Row SB3 Gravelly soil